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THESIS

MODELING THE COMBAT POWER POTENTIAL OF MARINE CORPS CLOSE AIR SUPPORT

by

Thomas C. Gillespie

September 1997

Thesis Advisor: William G. Kemple

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The collection of these values (i.e., kills per minute for each battlefield point) is suitable for display as a "combat potential surface," overlaid on a battlefield map. In this thesis, points of higher potential are keyed to brighter colors (e.g., red, yellow, orange). The end result is a battlefield visualization tool to assist commanders and staffs in CAS planning.

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MODELING THE COMBAT POWER POTENTIAL OF MARINE CORPS CLOSE AIR SUPPORT

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ABSTRACT

This thesis proposes a numerical measure of the combat power potential of U.S. Marine Corps close air support (CAS) aircraft. The combat power potential of a weapon system is defined as the rate at which the system could deliver lethal fire to any point on the battlefield, accounting for particular and relevant battlefield and enemy characteristics. This measure is expressed in units of "kills per minute," where each point is hypothesized to have an infinite supply of instantaneously replaced targets.

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THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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LIST OF SYMBOLS

a	aircraft type, a = F/A-18D or AV-8B
A_{F_i}	target acquisition degradation factor for FAC F_i, i = 1,2,3 . . .
Alert	aircraft alert status, *Alert* = *GA* (ground alert) or *AA* (air alert)
B_i	aircraft base i, i = 1,2,3 . . . , where B_i is a x,y pair of Cartesian coordinates
$d_{B_i \to xy}$	horizontal distance from base B_i to point x,y, i = 1,2,3 . . .
$d_{F_i \to xy}$	straight line (not necessarily horizontal) distance from FAC F_i to point x,y
$d_{OP \to xy}$	horizontal distance from the aircraft's orbit point to point x,y
F_i	Forward Air Controller, i = 1,2,3 . . . , may be ground-based or airborne
f_{ta}	fraction of enemy force of target type ta, $0 \leq f_{ta} \leq 1$, $\sum_{ta} f_{ta} = 1$
k	flight type, k = *del* (ordnance delivery flight) or *max* (maximum endurance flight)
$kias_{a,k}$	knots indicated air speed for aircraft a for flight type k
$K_{o\|ta}$	kills per sortie against target type ta given ordnance type o
L^*	minimum loiter time required over target for a sortie to be launched
n	number sorties allocated a CAS mission per 24 hour period
o	ordnance type, e.g., o = Mk-82, Mk-83, etc.
$o\|ta$	ordnance type o given target type ta

P	pilot proficiency degradation factor, $0 < P \leq 1$
PP_{CAS}	combat power potential of close air support
PP_{df}	combat power potential of direct fire weapons
PP_{if}	combat power potential of indirect fire weapons
R	sorties per minute, $R = \frac{n}{1440}$
$Range_a$	maximum flight endurance time for aircraft a, expressed in minutes of flight, e.g., $Range_{F/A-18D}$ = 103 minutes
$S_{F_i,xy}$	binary variable (0,1) to indicate line-of-sight between forward air controller F_i and point x,y
SSP_D	single sortie probability of damage
$SSPD_{o\|ta,te}$	averaged single sortie probability of damage against target ta, given ordnance o, and in general terrain type te
t	time (in minutes) measured from a reference time, t = 0, which marks the start of a 24 hour planning period
t'	time (in minutes) an air or ground alert aircraft receives a mission, measured from t = 0
t_{DEP}	clock time of aircraft departure for designated orbit point measured from t = 0
ta	target type, e.g., ta = tanks, infantry, etc.
T	threat degradation factor, $0 \leq T \leq 1$
tk	time (in minutes) required for ground alert aircraft to get airborne after receiving a mission
V	visibility degradation factor, $0 \leq V \leq 1$

x,y	Cartesian coordinates for points in a battlefield area
$Z_{a,Alert,xy,t}$	binary variable to indicate whether point x,y is within striking range of aircraft *a*, in status *Alert*, at time *t*

EXECUTIVE SUMMARY

The ability to concentrate forces at critical times and places on the battlefield, while maintaining the minimal forces elsewhere to deter defeat, is an essential quality of a successful commander. A battlefield visualization tool that can show a commander the impact of his decisions on his capability to mass his forces will surely aid him in perfecting that quality.

Previous work aimed at developing such a battlefield visualization tool has focussed on graphically depicting the "combat potential" of direct fire (e.g., machine gun, anti-tank missiles, etc.) and indirect fire (e.g., aritllery, mortars, etc.) weapon systems. This thesis extends this work by quantifying the "combat power potential" of the third principal combat arm available to a Marine Air-Ground Task Force Commander, close air support (CAS).

This "combat potential," or "combat power potential" as it is called in this thesis, is defined as ***the rate at which weapons systems could deliver lethal fire to any point on the battlefield, at any time, after accounting for particular and relevant battlefield and enemy characteristics.*** This measure is expressed in units of "kills per minute" for each battlefield point at each time

t, where each point is hypothesized to have an infinite supply of instantaneously replaced targets.

Determining the combat power potential of CAS is a two step calculation: first, calculating the lethality of CAS against a specified mix of target types (e.g., tank, infantry, armored personnel carriers) for each point on the battlefield under ideal battlefield conditions; second, scaling that lethality value by four conditions that may degrade CAS from its optimal effectiveness: pilot proficiency, the enemy anti-air threat level, the target acquisition methods of the forward air controller (FAC), and battlefield visibility.

The result of these calculations is a single value associated with each point in the battle area and each time *t*. The collection of these single point values is a "combat power potential surface" which is suitable for employment as a graphical display, superimposed upon the terrain display of the battle area. When each point value is appropriately keyed to color, the combat power potential surface readily displays to a commander his capacity to mass firepower in different battlefield areas and at different times.

I. INTRODUCTION

The principles of *mass* and *economy of force* dictate that a commander should bring to bear overwhelming combat power against the enemy at *critical* points (mass), while maintaining the minimal forces elsewhere to deter defeat (economy of force). A major challenge a commander faces is determining when and where those critical points occur on the battlefield, and deploying his forces in a manner that allows him to exploit them as they occur. Mastering this challenge is one of the arts of military command in war. A tool that allows a commander to visualize his potential for force massing that results from his tactical decisions will surely assist him in this endeavor.

Investigating the use of computer graphics to develop such a visualization tool was the aim of the U.S. Army's Battle Enhanced Analysis Methodologies (BEAM) project [Ref. 1]. Work done by Lamont [Ref. 1], Kemple and Larson [Ref. 2], and Larson, Kemple, and Dryer [Ref. 3] aimed at developing graphical displays of *combat potential* or *destructive potential*. Such displays allow the visualization of a force's ability to do damage to an enemy across a battlefield and at any time. These authors constructed quantitative expressions, cast in units of "expected kills per minute," for the lethal power of friendly weapon systems at all points over a specific

terrain at any time. Lamont and Larson *et al.* addressed themselves to direct fire weapons, while Kemple and Larson quantified the lethal power of indirect fire weapons. They then generated spatio-temporal graphical displays which permit the visualizing of combat potential for direct [Ref. 1:p. 48, 50-54] and indirect fire [Ref. 2:p. 31-33] weapons.

These displays are spatio-temporally dynamic in that they show combat potential, or the capacity to harm the enemy, at all points at any time. Naturally, no force can apply combat power to all points at any or all times. However, by visually depicting combat potential across the battlefield and over sequential times the display allows a commander to see where and when his combat potential is massed. Different tactical decisions will produce different possible massings of combat potential, and so different or varying *combat potential surfaces*. Thus, the graphical displays generated by the BEAM project serve as aids for tactical decision making, planning future operations, and training of battle staffs.

As a spatio-temporal representation of "combat power potential" (as it is later called in this thesis), this surface has four dimensions: time and three spatial dimensions.

Two of the spatial dimensions of the surface are the length and breadth of the battlefield. The third spatial

dimension is the surface *height*: the height at point x,y is the value in "expected kills per minute" that would occur if every weapon that could engage targets at x,y did so at their maximum sustained rate of fire, and if all killed targets were instantaneously replaced. This value changes over the length and breadth of the battlefield. A higher value for expected kills per minute at a given x,y point equates to a greater surface height. The force can bring more firepower to bear at that point than at a point with a lower surface height, i.e., lower expected kills per minute.

For the two dimensional graphical displays generated by the BEAM project, surface height is keyed to a recognizable color scheme: higher heights, indicating greater combat potential, are depicted in brighter colors, red and yellow. Lower heights are depicted in greens and blues. There are, of course, other ways to visually depict the varying combat power potential surface: surface height could be keyed to other colors, to intensity of color, or depicted as a three-dimensional surface in the proper computing environment.

The combat potential surface also has the quality of *durability* or *sustainability* through time. As time advances, the surface may grow or diminish in height at various points on the battlefield, reflecting the waxing and

waning of combat power potential as battlefield and other conditions change.

Thus far, these graphical displays have utilized quantitative expressions for the lethality of direct and indirect fire weapons. Yet the Commander of a Marine Air-Ground Task Force (MAGTF), the combat organization of U.S. Marine Corps forces, typically has at his disposal three types of weapon systems: direct fire weapons (e.g., tanks, heavy machine guns, anti-tank weapons, etc.), indirect fire weapons (e.g., artillery, mortars, etc.), and close air support (e.g., F/A-18, AV-8B aircraft). The purpose of this thesis is to provide a quantitative expression for the lethality of the third combat arm, close air support (CAS). This quantitative expression will be additive to those already developed for direct and indirect fire weapons. This will allow either visualization of combat potential by type of weapon system or a single, comprehensive visualization of the total combat potential of a MAGTF across the battlefield as the Commander desires.

This thesis is divided into eight chapters.

The first chapter, the Introduction, provides the general context for the thesis.

In the second chapter, a background discussion examines in greater detail previous work of the BEAM project in which the battlefield lethality of various weapons was quantified.

In the third chapter, a general method for determining the lethality of close air support against particular target types is described. CAS lethality is expressed as "kills per minute" to make it additive to the units of direct and indirect fire lethality.

In the fourth chapter, the limits that *time* and *space* impose on the availability of CAS are considered, and a method of incorporating those limits into the expression for CAS lethality is described.

In the fifth chapter, other battlefield factors that limit or degrade the efficacy of CAS lethality are examined, and a method of incorporating those limiting factors into the general expression for CAS lethality is presented.

The full and final model for CAS combat power potential is summarized in the sixth chapter.

The seventh chapter presents an example of a combat power potential surface based on lethality values for close air support calculated using the methodology developed in this thesis.

The eighth and last chapter is a general conclusion.

II. BACKGROUND

This chapter consists of four parts. In the first, the seminal work of Colonel T. Dupuy in quantifying weapon lethality is briefly examined, along with some broad differences and similarities to that of the BEAM project. In the second, the work of Lamont in quantifying direct fire weapon lethality is surveyed in greater detail. In the third part, Kemple and Larson's work in quantifying indirect fire lethality is examined. The fourth part develops a single, descriptive phrase for the "combat potential" or "destructive potential" index.

A. DUPUY AND THE QUANTIFIED JUDGMENT MODEL

One aim of combat modellers and analysts is to quantify the battlefield lethality of the heterogenous weapons available to a modern combat commander. One of the most thorough, if not well-received, attempts to do this in recent times was made by Colonel T. N. Dupuy (U.S. Army, Ret.) in his Quantified Judgment Model (QJM) [Ref. 4, Ref. 5]. Dupuy defines weapon lethality as "the inherent capability of a given weapon to kill personnel, or to make material ineffective in a given period of time, where capability includes the factors of weapon range, rate of fire, accuracy, radius of effects, and battlefield mobility" [Ref. 4: p. 19]. While Dupuy's final mathematical expression for weapon lethality is a dizzying collection of

factors (28 different factors for close air support), some derived from analysis of the weapon itself (e.g., rate of fire) and others from historical data (e.g., target dispersion), his fundamental method is very appealing.

Dupuy argues that a weapon's lethality can be quantified by combining two factors: 1) a weapon's "proving ground" lethality, i.e., "the maximum possible lethality under ideal conditions," and 2) "a variety of realistic combat variables, such as the effects of weather, terrain, season, mobility characteristics, and vulnerability" [Ref. 4:p. 30]. The former factor Dupuy calls the *Operational Lethality Index*, or OLI, and the latter *combat variables*. The product of OLI and combat variables is *combat power* [Ref. 4:p. 42] or *combat power potential* [Ref. 4:p. 46].

The specifics of Dupuy's approach have not been universally accepted amongst combat modelers and operations analysts, nor is his model suitable for all lethality calculations. Dupuy's approach generalizes combat potential over a terrain type, a method suitable for highly aggregated combat models. Further, Dupuy explicitly excludes time from direct consideration in his model [Ref. 4:p. 38]. These characteristics preclude direct application of much of Dupuy's work to the sort of spatio-temporal, high resolution, graphical display envisioned by the BEAM project and this author. Nevertheless, his general method of

establishing ideal lethality and then modifying it by battlefield conditions (albeit general ones) has been taken up by others working on the BEAM project, with some crucial differences.

The principal difference between work accomplished under the BEAM project and Dupuy is that in the former weapon "proving ground" lethality is modified by specific battlefield conditions, while the latter used general condition types. For instance, Dupuy modified "proving ground" lethality by a multiplier representing terrain, using one of twelve terrain categories [Ref. 4:p. 228]. Lamont, on the other hand, employed a high resolution approach in which line-of-sight between a firing position and every x,y point on the battlefield was calculated.

Also, BEAM project members used "expected kills per minute" as the dimension for combat potential, unlike Dupuy who used a dimensionless index called "combat power."

In the BEAM project's work, a graphical display of the resulting values for weapon lethality was created, called a "combat potential surface" by Lamont [Ref. 1:p. 36], and "destructive potential surface" by Kemple and Larson [Ref. 2:p. 31]. This combat potential surface ties weapon lethality to specific geographical points by including range, ground trafficability, observer locations, and line-of-sight in the calculations. The result is a "contour

map" of combat potential for a terrain area, with colors indicating relatively higher (e.g., yellow, red) and lower (e.g., green, blue) areas of combat potential [Ref. 2:pp. 31-33, Ref. 3:pp. 19-20]. Two important points regarding this work are:

1. The combat potential value, i.e., "expected kills per minute," for each point on the battlefield is not intended to predict actual kills expected of a weapon system in combat. Two aspects of the value make this interpretation impossible.

First, the value presupposes instantaneously and inexhaustibly replaced targets at the value's point, a clear impossibility.

Second, each point on the battlefield has such a combat power potential value associated with it at every time, representing the combat power that could be generated if every weapon capable of engaging targets at that point did so. This would require each weapon to fire at all points within its range simultaneously. This is also clearly impossible.

Rather, the value allows comparison between surfaces, or between various tactical alternatives considered by a commander. The tactical alternative with the higher expected kills per minute at point x,y could be expected to cause more damage to an enemy at x,y than that

with a lower expected kills per minute, but not necessarily produce the actual kill rate indicated by its combat potential value.

2. The calculation of combat potentials is not intended as an academic exercise only, but to serve as an aid to tactical decision making by displaying those values as a combat potential surface. Whether used to assist in combat, combat planning, or peacetime training, the combat potential surface is tied to a specific landscape. By altering his weapons mix or maneuvering his forces to different locations, a commander can create different combat potentials across the battlefield. Areas where a commander has created the ability to mass his fires will have greater combat potential, and hence display a higher combat potential surface. This is in distinction to Dupuy who never resolved his "combat power" index below the level of a general terrain type. For Dupuy, an entire battlefield has a single and unchanging combat power value for each force; the combat potential surface, on the other hand, has a value for each point on the battlefield, a value which changes continuously as the friendly force maneuvers.

With these points in mind, the extension of Dupuy's fundamental method to direct and indirect fire systems can be examined more closely.

B. DIRECT FIRE LETHALITY

Lamont [Ref. 1] adopted Dupuy's approach to calculating Operational Lethality Indices (OLI) for each weapon system on the battlefield after altering it for his own purposes (while keeping the same name; Lamont's OLI, however, is emphatically not the same calculation as Dupuy's OLI). For each point x,y on the battlefield, imagine a target which is instantaneously replaced by a target of the same type after being killed. To determine the expected number of kills of such instantaneously replaced targets, Lamont envisioned four factors that would effect the expected kill rate at a given point x,y:

1. Rounds per minute, or rate of fire, for weapon w against targets of type t, designated $R_{w,t}$, $R_{w,t} > 0$;

2. Probability of hit and kill of target type t by weapon w at range r, designated $p_{r,w,t}$, $0 \le p_{r,w,t} \le 1$;

3. Line of sight, a binary variable of 1 (if line of sight exists between weapon w and point x,y and the target is within range) or 0 (if no line of sight exists or if the target is beyond the weapon's range), designated $L_{w,t,xy}$; and,

4. Fraction of the enemy force of target type t, designated f_t ; $0 \le f_t \le 1$.

The last factor, f_t, is required to account for weapon platforms with multiple weapons, each of which is used to best effect against different target types and cannot be used simultaneously. For instance, the Bradley Fighting Vehicle has a Tube-launched, Optically-sighted, Wire-guided (TOW) missile for principal use against tanks, and a chain gun for use against armored personnel carriers (APCs). Each weapon has a different rate of fire and probability of kill against its intended target. By multiplying the OLI by the factor f_t, the resulting combat potential is adjusted to account for the different characteristics of the platform's individual weapons.

For instance, suppose that 20% of an enemy force consists of tanks, and 80% consists of APCs. Then the TOW, with its fire rate and kill probability against tanks, contributes 20% of the total combat potential, and the chain gun contributes the remaining 80%.

The combat potential for a force, then, is defined as the product of these four factors, summed over each target type and each friendly weapon; this is Lamont's OLI [Ref. 1:p. 44, Ref. 2:p. 26]:

$$CP_{df}(x,y) = \sum_w OLI_w(x,y) = \sum_w \sum_t f_t R_{w,t} L_{w,t,xy} p_{r,w,t}.$$

C. INDIRECT FIRE LETHALITY

Kemple and Larson (hereafter KL) extended Dupuy's fundamental approach to indirect fire weapons, specifically to artillery support. Adopting the same modifications of Dupuy as Lamont, KL postulated a maximum probability of kill for an artillery salvo against a tank or APC, using Dual Purpose Improved Conventional Munitions (ICM), as $P_{max} = 0.9$. They then multiplied this probability by the rounds per minute R_w an artillery piece is capable of firing, giving the *expected kills per minute*. This figure in turn is multiplied by the output of three degradation functions that account for the limitations that artillery units face in a particular battlefield. The range of these functions is between zero and one, representing:

1. $f_1(r_1)$; multiplicative degradation of kill probability due to the distance r_1, between an artillery forward observer (FO) and a point x,y, given that line of sight exists;

2. $f_2(r_2)$; multiplicative degradation of kill probability due to the distance r_2, between the point x,y, and a target reference point (TRP), i.e., a known point on the ground, such as a survey reference point; and,

3. $f_3(s)$; multiplicative degradation of kill probability due to the terrain trafficability at x,y,s,

incorporating the influence of soil conditions, vegetation, slope, obstacles, etc., on target speed.

Each of these degradation functions decreases in its argument: $f_i(x), i = 1,2,3;\ x = r_1, r_2, s$, such that $f_i(x) \to 0$ as the relevant measured quantity increases, and $f_i(x) \to 1$ as it decreases. Under ideal conditions, i.e., a stationary target with zero distance between the FO and the target and zero distance between a TRP and the target, $f_i(x) = 1,\ i = 1,2,3;\ x = r_1, r_2, s$, and no degradation of the expected kills per minute occurs. The destructive potential for indirect fire, which KL also call the sum of Operational Lethality Indices for each weapon w, is defined as [Ref. 2:p. 30]:

$$DP_{if}(x,y) = \sum_w OLI_w(x,y) = \sum_w R_w f_3(s) f_2(r_2) f_1(r_1) P_{\max}.$$

This is the essence of KL's approach to calculating "destructive potential" [Ref. 2:p. 30]. Two points should be noted:

1. Calculation of the three degradation factors is abstracted from any particular enemy target, but tied to a particular terrain area and trafficability. That is, for each point x,y on the battlefield, an infinite supply of instantaneously replaced enemy targets is hypothesized, and the three degradation factors (and line of sight) for that point are calculated. When this value is determined for

every point x,y on the battlefield, the result is the combat potential surface, or destructive potential surface, for the battlefield.

2. The common dimension of destructive potential for direct and indirect fire (i.e., expected kills per minute) allows the construction of a combined destructive potential surface by simply adding the destructive potentials of direct and indirect fire together for each point x,y. Similar potentials calculated for other weapons, e.g., close air support, can be added to these sums, to provide ultimately a cumulative destructive potential that reflects the summed potentials of a commander's full range of supporting arms.

This is not to suggest that the actual combat power generated from the potential is additive across weapon systems; it is not. Combat power is a non-linear aggregation that depends on many factors. See the discussion of combat potential and power in Section **D**.

At times a commander may want to view this combined destructive potential. At other times, however, the surface for e.g., indirect fire weapons alone, may be all he wishes to see. The destructive potential surface developed in this thesis will be capable of providing these aggregated or disaggragated views of destructive potential.

D. THE DYNAMICS OF COMBAT: POWER V. POTENTIAL

In an attempt to bring order and scientific rigor to the study of combat, Hughes states in his *Combat Science: An Organizing Study* [Ref. 6] that he

> . . . aims to fill a great need to clean up the language of warfare, so that war colleges can teach concepts unambiguously, officers can communicate their combat experience clearly, and analysts can report what they have learned to each other and to the officer leadership with less confusion. [Ref. 6:p. iv]

In this spirit, it seems advantageous to propose a single term or phrase that captures the "combat potential" of Lamont, the "destructive potential" of KL, and the "combat power" or "combat power potential" of Dupuy. Rather than muddying the waters with an arbitrarily chosen phrase, it also seems advantageous to base any descriptive term(s) on the only attempt to standardize the language of warfare analysis this author is aware of: the work of The Military Conflict Institute (TMCI) and Hughes [Ref. 6] and Hughes, *et al.* [Ref. 7]. To that end, a basic familiarity with some of the applicable axioms and definitions of these author's works seems in order.

Hughes offers the following definitions of *combat potential* and *combat power*:

> Combat potential is a reservoir of resources and skills, like infantrymen, arms, and training. The ammunition in a warship's magazine is a component of combat potential, as are the ship's

> fire control system and trained fire control technicians. [Ref. 6:p. iii]
>
> Combat power is the rate at which delivered combat energy affects the enemy [in a] battle. The results it achieves are in the form of casualties, destruction, fear, demoralization, and suppression of enemy movement, return fire, thought and initiative. Combat power is, and only can be, measured by its effect on the enemy. [Ref. 6:p. iii]

Elsewhere he elaborates,

> Potential is loosely like the capacity to accomplish work on a battlefield. It is not a shooting rate but a magazine capacity - the number of shots carried or arrows in a quiver. [Ref. 6:p. 3-3]

Combat potential, then, is the latent capacity to do the work of combat, to destroy the enemy's physical, mental, and spiritual assets for the purpose of dominating him. Combat power, on the other hand, does not exist without actual combat. Hughes further divides combat potential into two types:

> **Designed combat potential** is the notional capacity of a force to achieve useful results in combat when performing its intended function, and optimally trained, equipped, supported, motivated, and led. [Ref. 6:p. 3-2]
>
> **Available combat potential** is the actual capacity of a force to achieve useful results in combat in the existing situation with its existing organization, training, equipping, support, motivation, and leadership. [Ref. 6:p. 3-2]

Designed combat potential is potential abstracted the furthest from the circumstances of combat. It is the doctrinal organization of a unit, when it is manned to its

Table of Organization strength, equipped to its Table of Equipment level, and fully motivated and led by the best officers and non-commissioned officers. In short, it is an ideal, similar to Dupuy's OLI.

Available combat potential takes us one step closer to the condition of units actually engaged in combat by incorporating deficiencies in personnel strength and quality, equipment shortages or inadequate maintenance, and training and leadership shortfalls. However, available combat potential makes no reference to the degradations in ideal capacity caused by a particular environment or enemy posture. It purports to describe actual combat capacities just short of the battlefield.

In the context of these definitions, it can be seen that Lamont and KL have quantified neither pure combat potential nor pure combat power.

They have not quantified what Hughes *et al.* refer to as "combat potential" (designed or available) because their quantifications explicitly account for line of sight and other restrictions imposed by a particular battlefield.

They have not quantified combat power, either, because they do not consider enemy attrition in the combat potential surface.

What these authors have quantified is something *more* than combat potential, but *less* than combat power, what may be called *power potential*[1].

Power potential may be defined as ***the rate at which weapon systems could deliver lethal fire to any point on the battlefield, at any time, accounting for particular and relevant battlefield and enemy characteristics.***

Note that power potential may not necessarily precisely predict real casualty-producing capability.

Note, also, that this definition does not allow for "force multipliers," i.e., factors which amplify the rate of delivery or effect, of lethal fire. This is in distinction to Dupuy, who allows the factor of "Air Superiority" to range above one in value, thereby making it a variable with amplifying influence on the value of the OLI for close air support [Ref. 4:p. 230].

With this definition in hand, it remains to be seen how the power potential of close air support, PP_{CAS}, can be quantified. Following Dupuy's method, this involves two steps:

1. Determine the "proving ground" lethality of close air support, i.e., "the maximum possible lethality under ideal conditions" [Ref. 4:p. 30];

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[1]This term was coined by Profs. Hughes and Kemple in a discussion with the author regarding this thesis on 10 April 1997.

2. Identify and quantify the "variety of realistic combat variables" [Ref. 4:p. 30] that degrade the "proving ground" lethality of close air support.

III. CLOSE AIR SUPPORT LETHALITY

In this chapter, after defining "sortie," a method for calculating the "proving ground" lethality of close air support (CAS) will be presented. This method will consist of eight steps linked to the weaponeering procedures for CAS planning found in the *Joint Munitions Effectiveness Manual/Air Support - Visual Deliveries (JMEM/AS)* [Ref. 8] and *Joint Munitions Effectiveness Manual/Air-To-Surface -- Weaponeering Guide* [Ref. 11]. The end result of this chapter will be a mathematical expression for the lethality of CAS in units of expected kills per minute.

In accordance with the *MAGTF Aviation Planning* publication, a "sortie" is "an operational flight by one aircraft. (Joint Pub 1-02)" [Ref. 9:p. H-15]. Reference 10 defines "sortie" similarly as "one flight of one aircraft to conduct a single mission" [Ref. 10:Glossary, p. 13]. The same reference also defines "pass" as an "aircraft maneuver conducted to release weapons on a target" [Ref. 10:Glossary, p. 11]. Moreover, in the context of the *JMEM/AS*, "sortie" and "pass" are used interchangeably to mean a single aircraft's traversal over a target during which ordnance is, or could have been, released. Whenever multiple passes are referred to in the *JMEM/AS*, it is always explicitly stated as a "number of passes." In this thesis, therefore, "sortie" or "pass" will always mean *a single traversal by an*

aircraft over a ground target for the purpose of delivering ordnance.

The "kills per minute" for CAS, then, may be calculated by working through the following steps, each of which is explained in greater detail below:

1. Stipulate the appropriate target damage criterion for each target type.

2. Stipulate the desired probability of achieving the specified target damage criterion for each target type.

3. Determine the single sortie probability of damage for the applicable combination of ordnance and target type.

4. Determine the expected number of sorties required to achieve the specified target damage for each target type.

5. Calculate the "kills per sortie" for each target type.

6. Calculate the "sorties per minute" available from each applicable squadron for each target type.

7. Calculate the expected kills per minute for each target type.

8. Calculate the total expected kills per minute at each point x,y on the battlefield by adjusting for the expected mix of target types.

Step 1. Stipulate an appropriate target damage criterion. For each target type known to be in the battle area, a damage criteria must be specified. For example,

Reference 11 lists damage criteria for the following target types, among others:

Personnel:

> 30-Second Defense. Incapacitation that renders personnel incapable of functioning in a defensive role within 30 seconds.
>
> 5-Minute Assault. Incapacitation that renders personnel incapable of functioning in an offensive role within 5 minutes.
>
> 12-hour Defense. Incapacitation that renders personnel incapable of functioning in a defensive role within 12 hours. [Ref. 11:p. 6-1]

Armored Vehicles:

> M-Kill. Damage to the vehicle so that the driver cannot maintain controlled movement.
>
> F-Kill. Damage to the vehicle main armament so that direct fire on a target cannot be completed.
>
> K-Kill. Damage to the vehicle so that it is not economically feasible to make repairs and the vehicle is fit only for cannabalization of parts.
>
> P-Kill. Incapacitation of fighting troops in the vehicle. [Ref. 11:p. 6-2]

Step 2. Stipulate the desired probability of achieving the specified target damage criterion. Reference 11 provides "general recommendations for suitable probabilities of damage where the aim is to destroy or significantly damage the target . . . " [Ref. 11:p. 2-7]. For point targets, 0.70 to 0.80 is the recommended range for the probability of damage.

While it may be tempting for the planner to stipulate a desired probability of damage of .99 or even 1, higher values will require a greater number of passes or sorties to achieve the desired probability of damage. This in turn will reduce the power potential values for CAS due to the constraint on available sorties.

Step 3. Using the tables in the *JMEM/AS* [Ref. 8], determine the *single sortie probability of damage* (also referred to as *single pass probability of damage*, or *expected fractional damage*), denoted SSP_D, for a combination of ordnance and target. This is defined as the "probability of damaging a single target element randomly located within the target area" [Ref. 10:Glossary, p. 5]. This value is available provided the following information is known:

a. Ordnance type, e.g., Mk-83, Mk-82, Mk-81, bombs.

b. Target type, e.g., Personnel, Armored vehicles (vehicle type), Field and AA Artillery, Field Fortifications, Airfields, etc.

c. Terrain type, e.g., open, marsh grass, jungle tangle, rain forest, temperate forest, etc.

d. Target Posture, e.g., personnel standing, prone, or in foxholes, armored vehicles in the open, in revetments, etc.

e. Fuse, e.g., instantaneous, high setting, superquick, etc.

f. Delivery method, e.g., unaccelerated or dive delivery (2 or 4 Gs).

g. Release angle, e.g., 0, 10, 20, 30, or 45 degrees.

h. Release altitude, e.g., 2500 ft.

i. Circular Error Probable (CEP) of the ordnance, e.g., 5, 10, 20, or 40 mils.

Not all of this information is relevant for the type of calculations envisioned in this thesis. The value of power potential for CAS is sought for a <u>particular</u> combination of ordnance, target, and terrain type, but <u>abstracted from any particular</u> target posture, fuse type, delivery method, release angle or altitude, or CEP. In short, the SSP_D values in the *JMEM/AS* are too specific and contain too much detail for direct use.

An approximate or generalized SSP_D can be obtained by fixing the ordnance, target type, and terrain type variables, and averaging probabilities over the remaining variables: target posture, fuse, delivery method, release angle, release altitude, and CEP. In order to distinguish the resulting value from the SSP_D of the *JMEM/AS*, this *averaged single sortie probability of damage* will be denoted $SSPD_{o|ta,te}$ to indicate that the terrain type and a particular combination of target and ordnance type are specified while the other factors are averaged. The ordnance-target combination is expressed as *o|ta* to indicate that ordnance is selected for a *given* target type.

Step 4. Using the desired probability of damage determined in step two above, and the $SSPD_{o|ta,te}$ values from step three, determine the "*expected number of sorties for a desired fractional damage*" from the *JMEM/AS* charts [Ref. 8:Appendix A], denoted hereafter as $J_{o|ta,te}$. (Note: the *JMEM/AS* returns fractional values for $J_{o|ta,te}$.)

Step 5. Take the reciprocal of $J_{o|ta,te}$ to get the number of kills (where "kill" = achieving the desired damage) per sortie obtainable for a given combination of ordnance, target, and terrain type. Denoting this as $K_{o|ta,te}$, we have:

$$\text{kills per sortie} = K_{o|ta,te} = \frac{1}{J_{o|ta,te}} .$$

Step 6. Having determined the *kills per sortie*, it is necessary to calculate the number of *sorties per minute* that the supporting squadron is capable of providing to help fight the ground war. This is no simple calculation, but a complex function of aircraft reliability and maintenance factors, aviation logistics, and pilot availability. This calculation is done for us, however, in the *MAGTF Air Tasking Cycle*. This planning cycle, during which available air assets are matched to the MAGTF Commander's battle plan, consists of four phases [Ref. 9:p. 4/2-4/4]:

Phase I: Apportionment and Allocation.

1. Apportionment. In this phase, the total level of effort that should be dedicated to various types of air operations or tasks is determined for a given period of time, typically 24 hours, by priority or percentage.

2. Allocation. In allocation, the priorities expressed by the MAGTF Commander are translated into the total number of sorties (by aircraft type) available for each task. For instance, after consideration of maintenance factors and pilot availability, the Air Combat Element (ACE) Commander may determine that he has 40 sorties available for Offensive Anti-Air Warfare, 20 for air defense, and 40 sorties for Offensive Air Support (of which 15 may be for air interdiction, 10 for armed reconnaissance, and 15 for

CAS). It is during this phase that pre-planned air support requests are turned into scheduled and on-call missions.

Phase II: Allotment. During this phase the sorties previously allocated are now distributed to support the elements of the MAGTF. This permits the MAGTF elements to integrate their assigned sorties into their plan for fire and maneuver.

Phase III: Tasking. In this phase the division of sorties decided on in previous phases is put into formal orders and passed to the units involved in the form of an Air Tasking Order (ATO). The ATO provides specific sortie information to include, but not limited to, the mission number, the tasked and supported unit, the priority, mission times (time on station, time on target, etc.), mission location, ordnance type, and number and type of aircraft.

Phase IV: Scheduling. Squadrons assigned missions in the ATO now, upon receipt of the order, assign individual aircraft and air crews to specific missions and promulgate squadron flight schedules. This completes the Air Tasking Cycle.

For any given 24 hour period the Allocation portion of Phase I provides the number of sorties assigned a CAS mission. Taking advantage of that fact, let

n = number of sorties allocated a CAS mission (either scheduled or on-call) for a 24 hour period. Sorties per minute, *R*, are calculated as

$$R = \frac{n}{1440} \quad .$$

Step 7. Determine the kills per minute by multiplying *sorties per minute* and *kills per sortie*:

$$RK_{o|ta,te} \quad .$$

Step 8. Since the terrain type will be considered constant over the battlefield, the *te* subscript can be removed from *K* above as it will not vary for a given planning or combat scenario. On the other hand, a factor indicating the fraction of the enemy force made up of a target type must be added to reflect that a sortie is assigned a single target at a time. The resulting expression will be summed over all potential targets. In short, the total expected kills per minute for each point x,y on the battlefield within flight range of an attacking aircraft and for a 24 hour period is:

$$\sum_{ta} f_{ta} RK_{o|ta}, \qquad \forall \, x,y \qquad (1).$$

As previously mentioned, the *o|ta* subscript (which reads, "ordnance *o*, given target *ta*") is a particular combination of target and ordnance determined likely to produce the desired damage level. There are numerous sources for guiding selection of appropriate ordnance for a

target type, the *JMEM/AS* [Ref. 11] being one. This target-ordnance linkage is necessary to avoid postulating unlikely combinations of ordnance and target, such as Maverick guided missiles against personnel in the open, or firebombs (napalm) against tanks.

This eight step calculation provides the "proving ground," or ideal, lethality of CAS in units of expected kills per minute. This lethality is highly abstract, however, unmodified by spatio-temporal conditions that set sharp limits on CAS usefulness over a real battlefield. Addressing these spatio-temporal limits and incorporating them into (1) above is the subject of the next chapter.

IV. SPATIO-TEMPORAL LIMITATIONS ON CLOSE AIR SUPPORT

One of the great advantages of CAS aircraft is its ability to appear anywhere over the battlefield at any time to deliver lethal support to friendly forces on the ground. The "flip side" of this advantage is that CAS aircraft cannot be everywhere over the battlefield at all times; it has unambiguous time and space limitations which must be considered in planning. By appropriately selecting basing or refueling points and aircraft alert posture (i.e., air or ground alert), a commander can do much towards making decisive air support available at critical times in the battle. By incorporating time and space considerations in power potential calculations, the impact of such selections on power potential can be explicitly represented. First, however, the Marine Corps' planning and control measures for CAS must be understood.

The conduct of CAS as practiced by the Marine Corps falls into two general categories: *pre-planned* air support and *immediate* air support [Ref. 12, Ref. 13, Ref. 14]. *Pre-planned* support is CAS provided according to a detailed plan conceived before ground operations are executed; the Air Tasking Order (ATO) is such a plan. *Immediate* support is CAS designed to meet specific urgent requests by the ground forces which arise in the course of a battle and

cannot be reasonably foreseen. Pre-planned support can be further divided into two types:

1. Pre-planned Scheduled Missions (PSM)

Pre-planned scheduled missions (PSM) are CAS missions which receive detailed mission coordination and planning in advance. Requesting units specify a time for execution and the supporting aircraft is assigned a time-on-target (TOT). The target type and location are specified, as well as the supporting aircraft and suitable ordnance. For PSM, response time and availability are not issues: missions are flown by a schedule, and aircraft availability has already been settled in the Apportionment and Allocation Phases of air support planning.

2. Pre-planned On-Call Missions (POM)

POMs are CAS missions in which specific aircraft are loaded with ordnance for a specific target (or target type), and then placed in a ground or air alert status. The supported unit then requests execution of the mission when it is needed. These missions are also planned for in the ATO, with a time window specified during which the mission is likely to be requested. For POMs, response time and availability are critical issues: POM aircraft in a ground alert status far from the battle area will have a much greater response time than the same aircraft in an air alert status, i.e., flying in an orbit point just outside the

range of enemy anti-air weapons. The tradeoff is that aircraft in an orbit pattern require periodic refueling, making them unavailable for a period of time. Limitations on aircrew cumulative flight time, as well as periodic aircraft maintenance requirements, also set limits on the availability of air alert aircraft.

With immediate CAS, aircraft enroute to a pre-planned target must be diverted to meet an urgent request by a ground unit. Since immediate CAS is not planned, there is little a MAGTF or ACE commander can do to reduce response times and increase availability that he does not already do for PSM and POM aircraft. In effect, increasing the number (and flexibility) of POM and PSM sorties is the only way to meet the demand of random, immediate CAS requests. This makes the management of POM and PSM sorties of central importance to reducing response times and ensuring aircraft availability for ground forces.

The challenge, then, is to visualize PP_{CAS} in a way that highlights the CAS power potential available at different times over the battlefield as a function of tactical decisions by the commander. The offensive air support planner can then visualize different power potential distributions by altering the following factors under his control:

- the location of ground-alert POM aircraft, e.g., ship- or ground-based, the use of Forward Arming and Refueling Points (FARPs) or Vertical and Short Take-Off and Landing (VSTOL) pads in close proximity to the battle area;
- the location of the orbit point for air-alert POM aircraft, and,
- the number of aircraft in air alert and ground alert, respectively, awaiting on-call missions.

Let us assume that whether an aircraft can reach a point on the battlefield in order to attack a target is binary: the point either is or is not within the aircraft's range at the time of interest. Let us then use $Z_{a,Alert,xy,t}$, with a discrete range of zero and one, to indicate this capability for each point on the battlefield, where

a = aircraft type, i.e., F/A-18 or AV-8B,

Alert = alert status of the aircraft, i.e., *GA* (ground alert) or *AA* (air alert),

xy = point x,y on the battlefield, and

t = time elapsed from $t = 0$, expressed in minutes.

The two principal CAS aircraft (F/A-18D and AV-8B) in the Marine Corps inventory will typically travel at 500 kias (knots indicated air speed) in delivering ordnance on a target, but travel at different speeds to maximize their

endurance in the air (250 kias for the F/A-18D and 230 kias for the AV-8B) [Ref. 9:p. G-1]. These different speeds may be accounted for in calculating transit times, and can be reflected in the following notation:

$kias_{a,k}$ = knots indicated air speed for aircraft *a* for flight type *k*, where *a* = F/A-18D or AV-8B, and *k* = *del* (ordnance delivery speed) or *max* (maximum endurance speed), e.g., $kias_{AV\text{-}8B,max} = 230$;

B_i = aircraft base *i*, *i* = 1,2,3 . . . , where B_i is a x,y pair of Cartesian coordinates;

L^* = minimum loiter time over target required for a sortie to be launched.

We can also use *d*, subscripted to identify *from* and *to* locations, to designate horizontal (Euclidean) distance between two points of interest:

$d_{B \to xy}$ = distance from aircraft base *B* to point x,y. Other terms that will be required are:

$Range_a$ = maximum flight endurance time for aircraft *a*, expressed in minutes of flight, e.g., $Range_{F/A\text{-}18D} = 103$ minutes;

tk = time (in minutes) required for ground alert aircraft to get airborne after receiving a mission;

t' = clock time (in minutes from $t = 0$) an aircraft in air or ground alert status receives a mission.

a. Ground Alert

For on-call aircraft in ground alert, determining the value of the indicator variable $Z_{a,Alert,xy,t}$ for each point in the battle area and at time t is a matter of two calculations:

- Verifying that the time required to travel from the aircraft's base (its place of ground alert) to the point of interest and back is less than the maximum flight time for the aircraft type (condition 1 in the expression for $Z_{a,GA,xy,t}$ below);
- Determining, for each time t, whether the clock time of aircraft arrival over the target is less than t (condition 2 below).

For aircraft in ground alert at each base B_i, we determine the value of Z for each x,y on the battlefield, at each time t, for all aircraft a as follows:

$$Z_{a,GA,xy,t} =$$

$$\left\{ \begin{array}{l} 1 \text{ if } \left\{ \begin{array}{l} 1] \; 2 * \frac{d_{B_i \to xy}}{kias_{a,\max}} + L^* \leq Range_a; \text{ and,} \\ 2] \; t' + tk + \frac{d_{B_i \to xy}}{kias_{a,k}} \leq t \end{array} \right. \\ 0 \text{ otherwise;} \end{array} \right\}$$

$$\forall\, x, y,\ t,\ a, i.$$

For a given air support configuration then, i.e., given certain air base locations and readiness conditions of supporting squadrons, PP_{CAS} for a point of interest on the battlefield will change as t changes. Air combat power, from ground alert aircraft, will become available to the ground commander depending on:

- the proximity of ground alert aircraft to the Forward Line of Troops (FLOT), $(d_{B_i \to xy})$;
- time required to get ground alerted aircraft airborne and en route to the target, (tk);
- clock time the strike aircraft receives the execution order, (t').

b. Air Alert

For on-call aircraft placed in an air alert status in an *orbit point*, the situation is slightly different than that for ground alert aircraft.

An aircraft in an air alert status is burning fuel while circling in its orbit point awaiting a mission. The radius of action for the aircraft is steadily shrinking over time as its fuel diminishes. Since the aircraft must return to base whether a mission is assigned or not, the pilot must keep in reserve sufficient fuel to travel the distance to the base. As time progresses, the pilot's situation might be envisioned as depicted in Figure 1. As the aircraft's

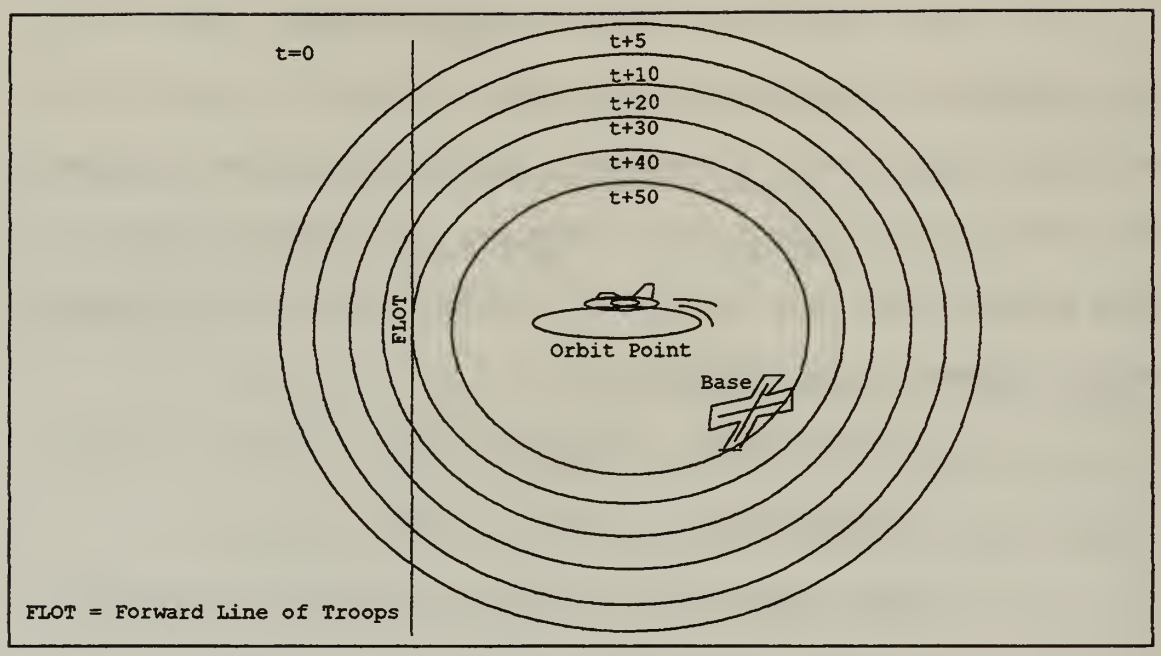


Figure 1. Shrinking Radius of Action for Air Alert Aircraft.

radius of action shrinks to *t+40* (where $t = 0$), the pilot might decide to return immediately to base, since he cannot strike targets forward of the FLOT. Alternatively, he might wait until *t+50*, when he must return to base or risk running out of fuel. It is not necessary to model this decision process of the pilot, but the shrinking radius of action over time must be reflected in PP_{CAS}, particularly forward of the FLOT.

To do this, we must be able to represent more information. Let us define the following symbols:

t_{DEP} = time of aircraft departure for designated orbit point;

$d_{OP \rightarrow xy}$ = distance from the aircraft's orbit point to point x,y.

For an aircraft in air alert, a target can be attacked if the sum of the distances between orbit point, target location, and base are less than the maximum distance the aircraft is capable of traveling at the time it is ordered to attack the target, after allowing for some minimum loiter time over the target. Since aircraft typically measure fuel consumption in terms of minutes of flight rather than terrestrial miles, we can exploit the formula *distance = speed * time* and express our units in terms of time. Therefore, a target at point x,y is within range of an air alert aircraft if

$$\frac{\text{total distance from OP to target and back to base}}{\text{speed of transit}} + L^* \leq \text{Remaining Flt Time} \quad (1a).$$

The time when an air alert aircraft receives a mission is critical because of its shrinking radius of action as it remains in its orbit point. The remaining flight time left to an air alert aircraft may be arrived at as follows:

$$\text{Elapsed Flight Time for Air Alert Aircraft} = t - t_{DEP}$$

$$\text{Remaining Flight Time} = Range_a - t + t_{DEP} \quad (2a).$$

The *speed of transit* which appears in (1a) above is not, however, a constant quantity. The varying speed of aircraft in different legs of its journey to and from a target, as noted above, must also be taken into account. Let us assume that an aircraft travels at its *ordnance delivery speed* in traveling from its orbit point to the

target, and its *maximum endurance speed* in traveling back to base after striking its target. Then,

$$\frac{\text{total distance from OP to target and back to base}}{\text{speed of transit}}$$

may be expressed as,

$$\frac{d_{OP \to xy}}{kias_{a,del}} + \frac{d_{xy \to B}}{kias_{a,max}} \qquad (3a).$$

Using (1a), (2a), and (3a), two conditions can be specified which jointly determine whether an air alert aircraft can strike at point x,y at each time t:

- the sum of the time it takes to transit from the orbit point to the target point, the time it takes to transit from the target back to base, and a minimum required amount of time over the target, must be less than or equal to the remaining flight time the aircraft is capable of at the time of mission assignment, that is,

$$\frac{d_{OP \to xy}}{kias_{a,del}} + \frac{d_{xy \to B}}{kias_{a,max}} + L^* \leq Range_a - t + t_{DEP};$$

- for each time t, the clock time of aircraft arrival over the target must be less than or equal to t, that is,

$$t' + \frac{d_{OP \to xy}}{kias_{a,k}} \leq t \ .$$

This yields the following binary variable:

$$Z_{a,AA,xy,t} =$$

$$\begin{cases} 1 \text{ if } \left\{ \begin{array}{l} \frac{d_{OP \to xy}}{kias_{a,del}} + \frac{d_{xy \to B}}{kias_{a,\max}} + L^* \le Range_a - t + t_{DEP}, \text{ and,} \\ t' + \frac{d_{OP \to xy}}{kias_{a,k}} \le t; \end{array} \right\} \\ 0 \text{ otherwise;} \end{cases}$$

$$\forall (x,y), t, a.$$

Combining the indicator variable Z with (1) gives the following calculation for PP_{CAS}:

$$Z_{a,Alert,xy,t} \sum_{ta} f_{ta} RK_{o|ta} \qquad \forall x,y\ Alert, t, a \quad (2).$$

This chapter has offered a way of incorporating spatio-temporal limitations on CAS availability over the battlefield by using a binary variable. The value of this variable is calculated for every point x,y on the battlefield and for every time t (minutes). The resulting expression (2) provides the power potential value of CAS modified only by the general limitations of physics and aircraft capacity. There are other limitations, however, imposed by particular battlefield conditions. If each of these conditions can be expressed as a number between zero and one, then expected kills per minute for actual battlefield/weapon system conditions can be expressed by multiplying (2) by these quantified conditions. This is the aim of the next chapter.

V. FACTORS DEGRADING CLOSE AIR SUPPORT LETHALITY

The ideal value of the power potential of CAS against any point on the battlefield at any time is degraded by a number of factors:

- the pilot's experience level;
- the degree of enemy air threat in the area;
- target acquisition methods; and,
- visibility in the battlefield area.

In this chapter, each of these four degrading factors will be examined in turn to assess its influence on CAS "proving ground" lethality.

A. PILOT EXPERIENCE LEVEL

The ability of a CAS pilot to deliver lethal fire to a designated target can be considered a function of two variables: training and combat experience. While combat experience may be interpreted as the number of combat flight hours a pilot has accumulated, collecting and analyzing this data for the purpose of assessing unit experience is too cumbersome for ready use in the sort of decision aid contemplated in this thesis.

On the other hand, aviation training, as a measure of pilot proficiency, is monitored in the Fleet Marine Force (FMF) by a comprehensive Training & Readiness (T&R) Program [Ref. 15] that assigns a Combat Readiness Percentage (CRP) to individual aviators based on their proficiency and

currency in specific aviation skills. The CRP has four levels [Ref. 15:p. 2-3]:

Combat Capable	60% CRP
Combat Ready	70% CRP
Combat Qualified	85% CRP
Full-Combat Qualified	100% CRP

Classification of a pilot into one of these four areas depends on the number of events in his aircraft specialty (MOS) he has satisfactorily completed (i.e., demonstrated *proficiency*) within a specified time (i.e., the re-fly factor). A pilot increases his CRP by demonstrating proficiency in more events in his MOS syllabus; he maintains his CRP by demonstrating proficiency in events he has completed in the past within the re-fly time for those events. Demonstrating this proficiency, or re-qualifying, within the re-fly time is how pilots maintain their *currency*, yet only by showing proficiency in new events can a pilot increase his CRP.

Currently, squadrons maintain an automated database of CRPs for all squadron members, called the Aviation Training Information Management System (ATRIMS). The average CRP of all aviators within a unit is a measure of the unit's combat readiness. Scaling this value to between zero and one (divide by 100) allows it to be appended to (2) as a degrading factor:

$$\text{Pilot Proficiency} = P = \frac{\text{unit average CRP}}{100},$$

which gives,

$$PZ_{a,Alert,xy,t} \sum_{ta} f_{ta} RK_{o|ta} \qquad \forall x,y\ Alert,t,a \quad (3).$$

B. THREAT LEVEL

The degrading influence of the enemy anti-air threat on CAS effectiveness is observed principally on the spatial aspect of power potential.

Spatially, threat level reduces kills per minute, i.e., the "height" of the power potential surface, by forcing CAS aircraft to employ tactics that reduce CAS accuracy. There is no prescribed tactic for each level of threat that will invariably be employed in each situation. Air tactics will vary from squadron to squadron, pilot to pilot, and even battle to battle. For instance, the classic ingress tactic for CAS missions is to fly as close to the earth as practical until the target area is reached. At that point, the aircraft pops up to deliver its ordnance and then performs a similar low level egress. This tactic relies heavily on surrounding elevated terrain to mask the aircraft's signature from electro-optical sensors. During the Gulf War, however, many squadrons found that a high ingress altitude, just out of range of shoulder-fired surface-to-air missiles, allowed them to deliver ordnance with a high degree of accuracy while keeping the aircraft out of harm's way [Ref. 16].

The threat to friendly aircraft operation over the battlefield is doctrinally divided into three levels, *low, medium,* and *high,* depending on the type of antiaircraft weapon systems present on the battlefield [Ref. 14:p. 2-2]. Each division is characterized by different weapon systems in order of increasing lethality:

- **Low**

    0. small arms
    1. medium AA weapons
    2. AAA w/limited optical acquisition (not integrated)

- **Medium**

    3. Radar, electro-optical acquisition (not fully integrated)
    4. Fully integrated fire control, degraded due to terrain, weather, or other factors

- **High**

    5. Fully integrated fire control, not degraded
    6. Mobile SAMs
    7. Early Warning Radars
    8. Electronic warfare
    9. Interceptor aircraft

Due to the wide variety of possible responses to each threat level, there is no known function that relates threat level to its consequent impact on CAS effectiveness. The only undisputed fact is that increased threat equates to decreased CAS effectiveness. For this reason, in the absence of a more precise functional relationship between the two variables, a linear relationship will be adopted.

The value of the threat degradation factor, therefore, is arrived at as follows: the absence of an anti-air threat means *T* (threat degradation factor)= 1. For each of the ten threat levels present on the battlefield, starting with small arms, reduce *T* by one tenth of its rank. For instance, if mobile SAMs are present on the battlefield, then *T* = 1 - (.1*6)=.4 . In general, the threat degradation factor is calculated as follows:

$$T = 1 - .1*(\text{threat rank})$$

Appending *T* to expression (3) above gives:

$$TPZ_{a,Alert,xy,t} \sum_{ta} f_{ta} RK_{o|ta} \qquad \forall x,y\ Alert,t,a \quad (4).$$

A second factor which heavily influences CAS accuracy is *target acquisition* method.

C. TARGET ACQUISITION METHOD

"Target acquisition" is the visual search process involving three events: target detection, target recognition, and target identification. When Laser Guided Bombs (LGBs) or laser spot trackers (LSTs) are used, the

search process includes non-visual "sighting" by an aircraft/weapon sensor system which detects reflected laser energy. In either case, the presence of a Forward Air Controller (FAC) who directs the aircraft or weapon to the target is critical to a successful attack [Ref. 17].

A ground- or air-based FAC is a required ingredient in any CAS action. U.S. Marine Corps aviation doctrine [Ref. 17] mandates positive control of aircraft conducting CAS missions by a FAC. This control consists of the ground- or air-based FAC clearing an attacking aircraft ("cleared hot") to release ordnance on the designated target. Though the *reasonable assurance* doctrine allows a CAS aircraft, under certain circumstances, to release ordnance without being "cleared hot" by a FAC [Ref. 17], a FAC is still required to mark and/or "lase" the target for the attacking aircraft. *Reasonable assurance* is rarely invoked in peacetime, however, and is unlikely to be invoked in war unless battlefield conditions are unusually grave. Should that occur, CAS aircraft are still likely to receive terminal guidance to a target by an officer or Staff NCO with training in CAS procedures.

FAC guidance, then, is virtually a certainty in any minimally controlled battlefield situation, whether the ordnance is LGB or unguided bombs. How that guidance

impacts on CAS accuracy is a function of the FAC's method of designating the target.

Generally speaking, FAC methods can be roughly divided into two classes: 1) those in which the FAC uses laser range-finding or laser-designating equipment to "paint" the target with a laser beam, an example of the latter being the Modular Universal Laser Equipment (MULE), and 2) those in which the FAC relies upon his own ability to judge the range and bearing of a target from his own location or that of a prominent terrain feature or mark (e.g., smoke or phosphorous mark). In the first class, the target designating or ranging method is quite accurate; although "false lasing," which occurs when the FAC unknowingly lases intervening terrain rather than the intended target, is a possibility, it is sufficiently unlikely to occur when the FAC is properly trained that it can be dismissed. Consequently, the use of lasers to designate targets should present no degradation to CAS accuracy at all.

Letting A represent the degradation factor attributable to target acquisition methods and the subscript L refer to laser methods of target designation or ranging, we have:

$$A_L = 1.$$

When laser devices are not available, however, the FAC must rely on his own ability to judge the distance of the

target from his location or from a prominent terrain feature or battlefield mark off of which he can guide the CAS pilot. Considerable error can be introduced here in the FAC's ability to judge distance, and this error must be quantified and introduced into the power potential expression for CAS.

Over the last few decades, there has been a fair amount of research conducted by experimental psychologists toward developing a theory of space perception that relates true distance, measured as a Euclidean straight line, to estimated distance by human subjects. Attempts at determining the functional relationship between true distance and estimated distance have, in general, dealt with two types of distance judgments: *egocentric* and *exocentric*. *Egocentric* distance judgments are those in which the subject estimates the distance between himself and an object; *exocentric*, or *interobject*, distance judgments, are those in which the subject estimates the distance between two objects in a field of view. Both types of distance judgments relate to FAC methods. While mathematical models exist in the literature of experimental psychology for both egocentric and exocentric distance judgments, there are advantages and disadvantages to using either in calculating combat power potentials. Each type of distance judgment and its model will be examined in turn.

1. Method A: Egocentric Distance Judgments

Field experiments with human subjects have consistently shown that they misjudge the distance from themselves to an object, and that the magnitude of this judgment error changes as the true distance to the object increases [Ref. 18, Ref. 19, Ref. 20]. The nature and degree of that misjudgment has been in some dispute, however, with defenders for each of the four possible alternatives: a nonlinear increasing [Ref. 19], nonlinear decreasing [Ref. 20], linear increasing [Ref. 21], or linear decreasing [Ref. 22] relationship.

While it is not the purpose of this thesis to resolve this disagreement, it must be noted that, of the research referenced above, only in the experiments of Galanter & Galanter [Ref. 19] were true distances approximating those under which a FAC would presumably operate used, i.e., 183 to 9017 meters [Ref. 19:p. 302]. Each of the other researchers listed above conducted their experiments in small open areas of 20 meters in diameter, and then extrapolated their findings across distance in general. It is not unlikely, however, that errors in judging distance that appear linear over relatively small distances (0-20 m) might become nonlinear over larger distances (up to 10 km).

In any event, after conducting field experiments in which subjects estimated the slant range of an aircraft passing in front of them at an altitude of 200 feet, Galanter & Galanter found that the relationship between magnitude estimates and true distance could be expressed by the following function:

$$\text{estimated distance} = (\text{true distance})^{n}$$

where n = 1.25. This relationship, and the value of n, have been consistently reproduced by other researchers [Ref. 23, Ref. 24] under similar experimental conditions. The value of n = 1.25 indicates that errors in judging distance increase with true distance at an increasing rate, i.e., they are non-linear. Graphically, the relationship appears in Figure 2.

In order to fit this model into combat power potential as a degrading factor, it is necessary to convert the relationship between true distance and estimated distance into a value ranging from zero (completely ineffective) to one (no degradation of CAS effectiveness). It is also necessary to include a distance scaling factor which reflects the limits of a FAC's usefulness. At some distance from the FAC, his ability to guide aircraft to a target becomes negligible. The curvature of the earth alone presents a natural barrier to a FAC's line of sight, though

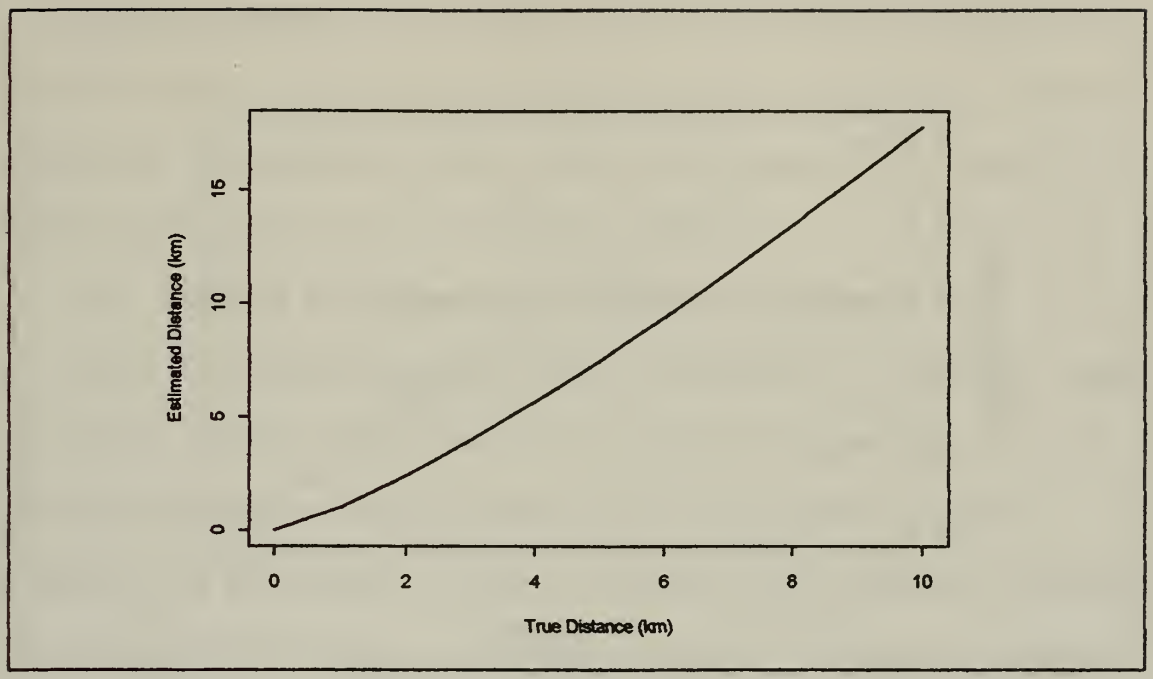


Figure 2. Estimated Distance v. True Distance, Estimated distance=(true distance)$^{1.25}$

elevation may extend that barrier. However, setting a large distance as the FAC's limit contradicts the character of *close* air support, which typically operates close to the FLOT. It may well be questioned whether distances beyond ten kilometers from the FLOT can still be considered as falling within the purview of close air support.

Let 1/b = scaling factor, where b > 0. Then, b = the maximum range of FAC effectiveness, expressed in kilometers. Using this scaling factor and applying the appropriate conversion, produces:

$$A_H = 1 - \left(\frac{x}{b}\right)^{1.25} \qquad 0 < b \ ,$$

where the subscript H indicates target acquisition

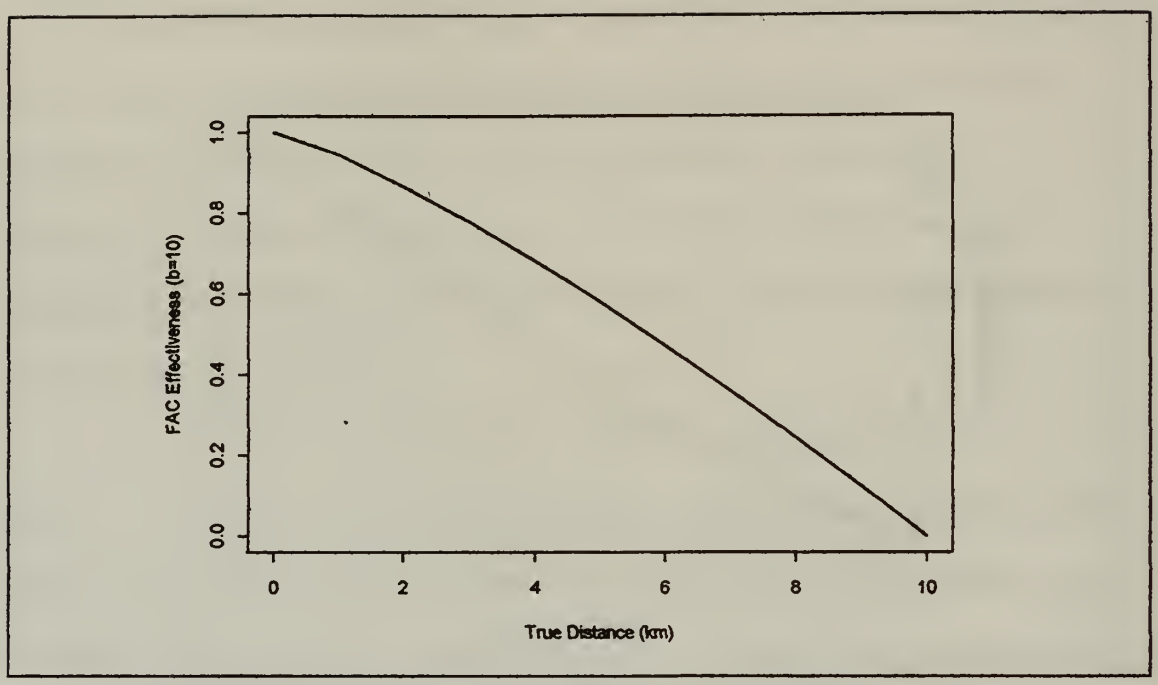


Figure 3. FAC Effectiveness v. True Distance, A_H=FAC Effectiveness=$1-\left(\frac{\text{true distance}}{b}\right)^{1.25}$, b = 10 .

methods that involve subjective distance estimation without laser devices, and where x = true distance (km).

For example, setting b = 10 to indicate that beyond 10 km the FAC's effectiveness is zero produces Figure 3.

In summary, Method A involves modeling a FAC's effectiveness as a function of the straight line distance between his location and all points within the scaling factor of b km. Since more than one FAC may be present on the battlefield, the subscript F_i is used where i = 1,2,3, ... This method may be denoted as:

$$A_{F_i} = \left\{ \begin{array}{l} A_{F_i,L}=1 \text{ for laser designating;} \\ \\ A_{F_i,H}=1-\left(\frac{x}{b}\right)^{1.25} \text{ for subjective distance judging, where scaling factor b > 0.} \end{array} \right\}$$

The principal advantage to using Method A is that it is based on field experiments which closely resembled, in the distances experimented over, the distances a FAC would likely operate at while directing CAS.

2. Method B: Exocentric Distance Judgments

The principal disadvantage to Method A is that it does not model errors in *exocentric* distance judgments, one of the most common methods a FAC uses to provide aircraft guidance to a target. If the FAC does not guide an aircraft to a target by using a prominent terrain feature or smoke mark as an offset point, he will surely use the first round miss of the attacking
aircraft to guide subsequent strikes. In short, exocentric distance judgment is an essential part of the FAC's function when working without laser equipment.

Experimentation has shown [Ref. 21] that two principal factors influence the amount of error involved in estimating the distance between two objects, or *interobject* distance: the true interobject distance and the visual angle along the viewer's line of sight.

Visual angle is the angle "taken at the position of the observer, between the two lines of sight when the observer looks first at one of the objects and then at the other" [Ref. 21:p. 251]. Variation in visual angle can arise from three sources: 1) *alignment* change with respect to the line

of sight (alignment is defined "by the angle formed between the line of sight of the subject and a line segment connecting the two objects" [Ref. 21: p. 251]); 2) a change in *viewing distance* between the observer and the midpoint of the interobject distance between two objects; and, 3) a change in *true distance* between the two objects. See Figure 4.

Based upon field experiments in a 20x20 meter field with eight viewing subjects, Levin & Haber [Ref. 21] determined that the relationship between estimated interobject distance (eid), true interobject distance (tid), and visual angle (va, degrees) is an increasing linear one with the following form [Ref. 21:p.252]:

$$eid = (1.108 * tid) + (0.164 * va).$$

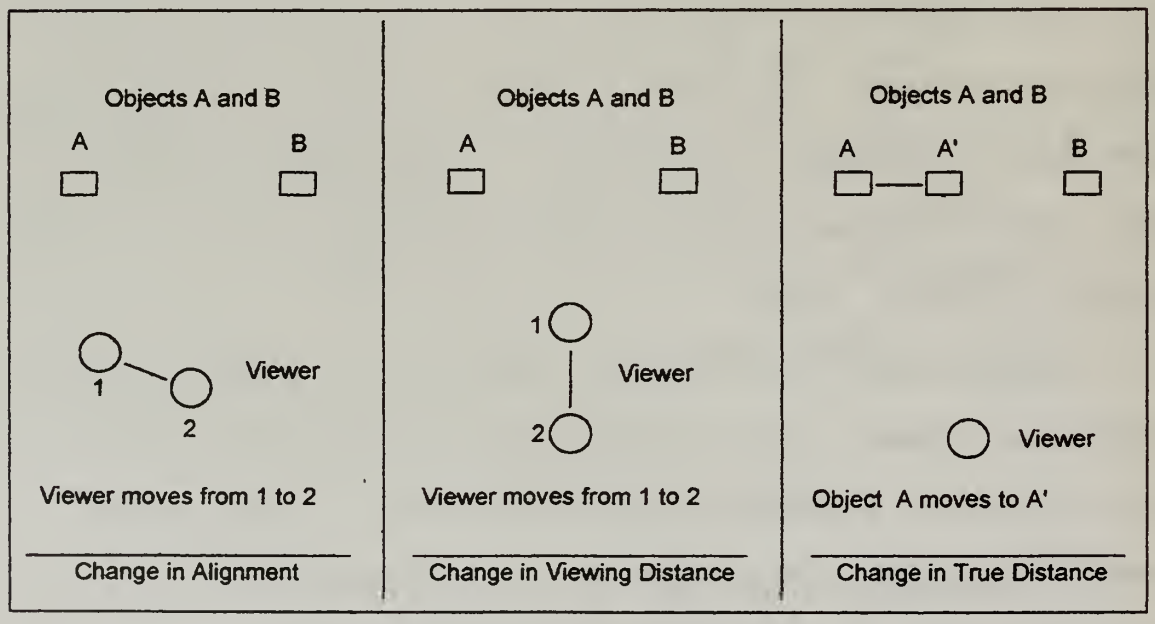


Figure 4. Visual Angles.

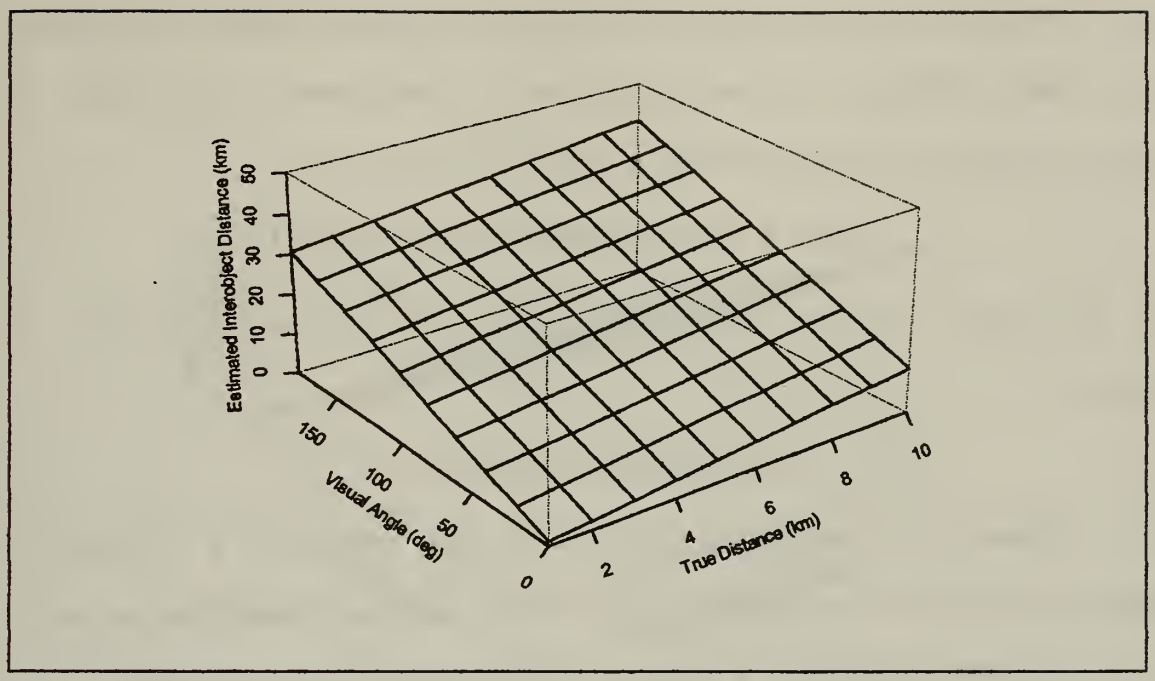


Figure 5. Estimated Interobject Distance (eid) v. Visual Angle (va) and True Interobject Distance (tid), eid = (1.108 * tid) + (0.164 * va).

This relationship indicates that subjects consistently *overestimate* interobject distance as both true interobject distance and visual angle increase. This function is graphically depicted in Figure 5.

In order to convert this linear relationship into one indicating FAC effectiveness, it is necessary to convert the function so that the ordinate ranges from zero to one. Following the argument of Method A, it is also necessary to scale the function to indicate the interobject range and visual angle at which FAC effectiveness is zero.

This scaling factor does not bear so obvious a relationship to distance and angle as it does with Method A above. As before, let b = scaling factor. Then, converting

the ordinate of the previous graph to range between zero and one, and invoking the scaling factor, we have (using the same notation used to denote Method A):

$$A_H = 1 - \left[\frac{1}{b} * (1.108 * tid + 0.164 * va)\right] .$$

It is clear that A_H equals zero when the following holds true:

$$b = 1.108 * tid + 0.164 * va .$$

Since this function is linear, the value of b is found when *tid* and *va* are maximized. The maximum possible value of *va* is 180 degrees, a value limited by the way *visual angle* is defined. Setting *va* = 180, the above equation becomes,

$$b = 1.108 * tid + 29.52 .$$

True interobject distance (tid), on the other hand, has no such limit (other than the natural curvature of the earth). There may be some argument, however, to support the contention that a FAC will rarely operate with true interobject distances greater than one kilometer. Setting *tid* = 1, then, gives b = 30.63. Using this value for b in the function for FAC effectiveness produces the two plot views depicted in Figures 6 and 7. Combining this

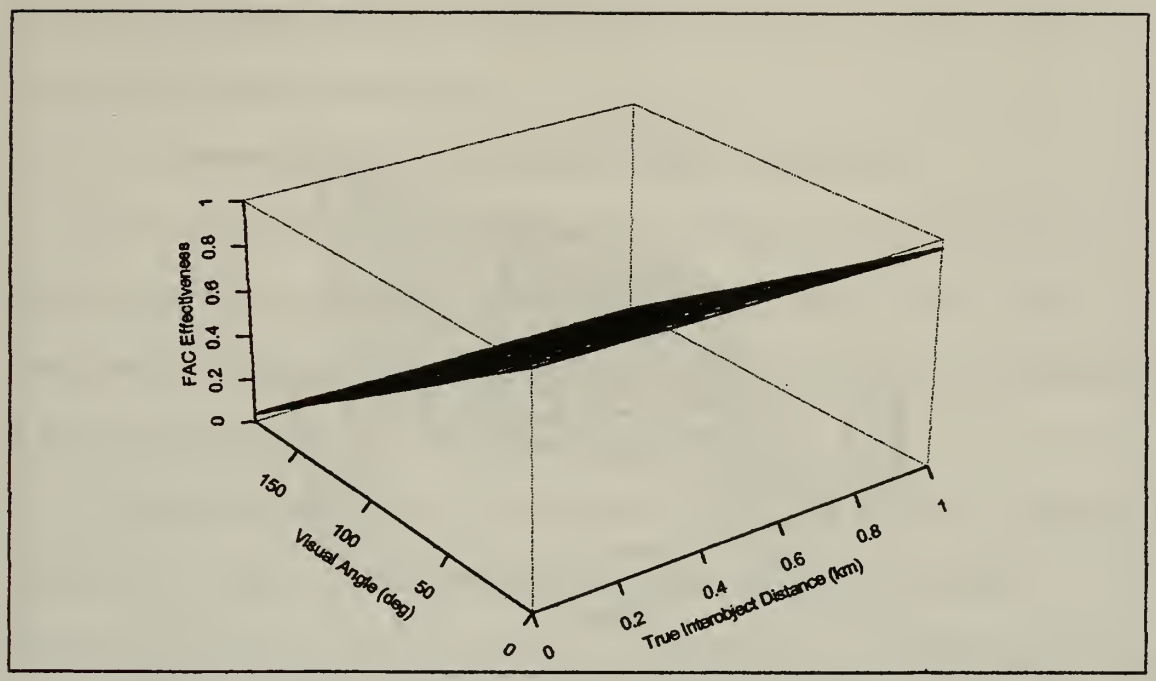


Figure 6. First View of FAC Effectiveness v. True Interobject Distance (km) and Visual Angle (degrees), A_H = FAC Effectiveness=1 $-\left[\frac{1}{30.63} * (1.108 * tid + 0.164 * va)\right]$.

expression with that for laser-designating produces:

$$A_{F_i} = \left\{ \begin{array}{l} A_{F_{i,L}} = 1 \text{ for laser designating;} \\ \\ A_{F_{i,H}} = 1 - \left[\frac{1}{b} * (1.108 * tid + 0.164 * va)\right] \text{ for subjective distance judging, where scaling factor } 0 < b \leq 31. \end{array} \right\}$$

The principal advantage of using Method B to characterize FAC effectiveness is that it reflects to a greater degree than Method A the actual procedures that FACs generally employ when guiding an aircraft to a target without laser equipment. FACs typically rely on interobject, or exocentric, distance judgments more than egocentric ones.

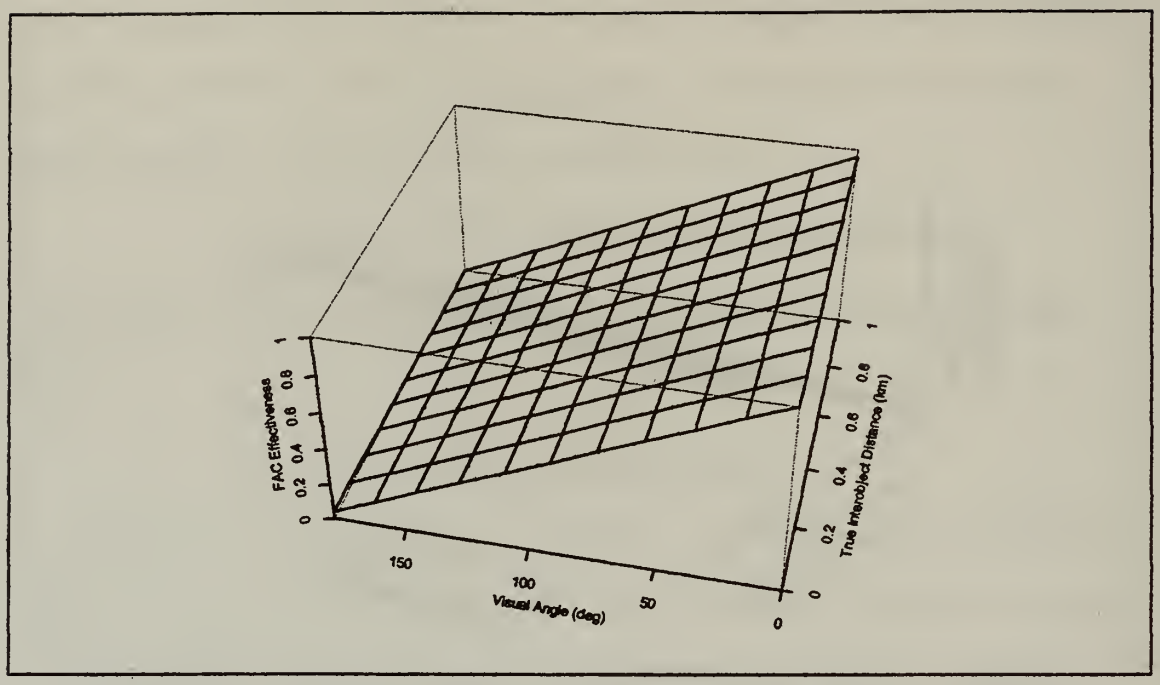


Figure 7. Second View of FAC Effectiveness v. True Interobject Distance (km) and Visual Angle (degrees), A_B = FAC Effectiveness=1 $-\left[\frac{1}{30.63} * (1.108 * tid + 0.164 * va)\right]$.

One disadvantage, however, is that the linear model that Method B is based on was generated from experimental conditions using distance judgments over short ranges [Ref. 21:p. 251], not the longer ranges a FAC will typically operate at (500 meters or more). This means that this model may substantially misrepresent the error involved in judging interobject distance.

Another disadvantage to using Method B is that it requires more information than Method A to use. For the sort of graphical device envisioned for depicting combat power potential surfaces, users would have to know the locations not only of FACs, but their target reference

points as well. While this is not impossible, it is not required to use Method A.

3. Forward Air Controller (FAC) Airborne

Not all FACs are ground-based. The use of airborne FACs in spotter aircraft is increasingly prevalent, and frequently a pilot in another attack aircraft will serve as a FAC for follow-on missions.

The effectiveness of airborne FACs, or FAC(A)s, may be modelled in much the same manner that Method B models ground-based FAC effectiveness. The FAC(A)'s value comes in using ground-based visual cues to guide an attacking aircraft to the target. Interobject distance judging, then, adequately characterizes the FAC(A)'s method.

Further, since attack aircraft may also be equipped with laser designating equipment (the F/A-18D is so equipped), laser designation of targets by FAC(A)s is also a possibility. Therefore, the same piecemeal function may be used for FAC(A) that was used for ground-based FACs, assuming Method B:

$$A_{F_i} = \left\{ \begin{array}{l} A_{F_{i,L}} = 1 \text{ for laser designating;} \\ \\ A_{F_{i,H}} = 1 - \left[\frac{1}{b} * (1.108 * tid + 0.164 * va) \right] \text{ for subjective distance judging, where scaling factor } 0 < b \leq 31. \end{array} \right\}$$

4. Forward Air Controller (FAC) Line-of-Sight

One last consideration that must be addressed before appending a target acquisition degradation factor to (4) is line-of-sight. Obviously, a FAC, airborne or ground-based, cannot provide terminal guidance to a target he cannot see. Therefore, a binary variable will be used with discrete range of zero and one depending on whether line-of-sight between a FAC and point x,y exists. This variable, denoted $S_{F_i,xy}$, is subscripted to tie it to each battlefield FAC in case more than one exists. Therefore, let $S_{F_i,xy}$ be defined as follows:

$$S_{F_i,xy} = \left\{ \begin{array}{l} 1 \text{ when line-of-sight exists} \\ \text{ between FAC } F_i \text{ and x,y;} \\ \\ 0 \text{ otherwise;} \end{array} \right\} \qquad \forall x, y, i \ .$$

The only complication that arises in the use of $S_{F_i,xy}$ occurs when more than one FAC has line-of-sight to a point x,y. To resolve the question of which FAC to use to calculate expected kills per minute for point x,y, we stipulate that the FAC *closest* to x,y (and having line-of-sight) is used to determine the power potential surface height at that point. Since FAC(A)s will almost always be further from any ground point than ground-based FACs, this implies that ground-based FACs will always be used to calculate power potential except at those points not directly visible to them. At those points, FAC(A)s will be

directly visible to them. At those points, FAC(A)s will be used to calculate power potential. This accords with common sense and actual practice.

Appending A_{F_i} and S_{F_i} to expression (4) gives the following:

$$S_{F_i,xy} A_{F_i} TPZ_{a,Alert,xy,t} \sum_{ta} f_{ta} RK_{o|ta} \quad \forall x, y, F, Alert, t, a, \quad (5).$$

D. VISIBILITY IN THE BATTLEFIELD AREA

Battle space visibility plays a critical role in the complicated process of target acquisition. Environmental conditions (e.g., airborne dust or sand, night, dusk, or daylight), weather (e.g., rain, snow) and battlefield conditions (e.g., smoke, vehicle exhaust), all help determine minimum visibility distances. While modeling moment-to-moment visibility conditions is not the aim of this thesis, a general visibility factor for the battle space should be included in PP_{CAS} to reflect the added difficulties involved in acquiring targets under less than ideal visible conditions.

It is not disputed that a diminution of visibility has a negative effect on the target acquisition ability of pilots. Laser guided weapons are not immune to this effect, either: fog, smoke, and other particle-based obscurants all serve to absorb laser energy, diminishing and scattering the beams. How is this negative effect to be modelled?

In field experiments supervised by the U.S. Army's Night Vision and Electro-Optical Laboratories (NVEOL), it was found that the time to detection of a target made available for detection at $t = 0$ could be modelled by the (slightly modified) exponential distribution [Ref. 26:Chapter 4]. Only one such probability model, however, can be descriptive for a given environment; in short, the exponential model, with a given parameter and modification, assumes a constant visibility environment. Yet it is the effect of a *varying* visibility environment that is needed here.

For the sake of model tractability, the effect of changes in visibility conditions will be modelled as linear changes in the acquisition capabilities of pilots, despite the exponential character of detection probability under a given environment. Specifically, visibility degradation will degrade CAS effectiveness linearly.

This definition of the visibility degradation factor requires that the model user provide some measure of the visibility conditions under which the combat is or will be occurring. This is the Maximum Visibility Distance (MVD): the maximum distance pilots are able to see through the atmosphere. This value must be obtained externally to the model, either from real visibility conditions or conditions imposed by war gaming.

The point at which visibility no longer has a degrading effect on CAS effectiveness may be set to 10 km to accord with the 10 km limit on FAC effectiveness employed above. Clear visibility of 10 km (over 32,000 ft) satisfies the requirements of *close* air support: target acquisition and attack can be adequately performed under these environmental conditions. Accordingly, the expression for a battlefield visibility degradation factor is as follows:

$$V =$$

$$\left\{ \begin{array}{l} \dfrac{\text{Maximum Visibility Distance (MVD)}}{10} \text{ for } 1 \leq \text{MVD} < 10 \text{ km}, \\ \\ 1 \text{ for MVD} \geq 10 \text{ km}. \end{array} \right\}$$

Including this visibility factor in PP_{CAS} gives:

$$VS_{F_i,xy} A_{F_i} TPZ_{a,Alert,xy,t} \sum_{ta} f_{ta} RK_{o|ta} \qquad \forall x, y, F, Alert, t, a, \quad (6).$$

The resulting value of V will be determined by the MVD, which is itself determined by strike planners or wargamers based on actual or simulated battle space conditions.

VI. SUMMARY

In summary, this thesis presents a method for quantifying the combat power potential of U.S. Marine Corps close air support. The resulting values are suitable for display as a spatio-temporally dynamic combat power potential surface. This surface, expressed in units of kills per minute, can assist decision-makers in combat, combat planning, and training, to visualize the battlefield and the lethality contribution of CAS.

The combat power potential for CAS is calculated by:

$$VS_{F_i,xy}A_{F_i}TPZ_{a,Alert,xy,t}\sum_{ta} f_{ta}RK_{o|ta} \qquad \forall x,y,F,Alert,t,a, \ ,$$

where

V = visibility degradation factor, $0 \leq V \leq 1$;

$$S_{F_i,xy} = \left\{ \begin{array}{l} 1 \text{ when line-of-sight exists} \\ \text{ between FAC } F_i \text{ and x,y;} \\ \\ 0 \text{ otherwise;} \end{array} \right\} \qquad \forall x, y, i$$

A_{F_i} = target acquisition degradation factor for FAC F_i , $i = 1,2,3 \ . \ . \ . \ ;$

T = threat degradation factor;

P = pilot proficiency degradation factor;

f_{ta} = fraction of enemy force of target type ta;

R = sorties per minute $R = \frac{n}{1440}$, n = no. sorties allocated a CAS mission per 24 hour period;

$K_{o|ta}$ = kills per sortie for against target type *ta* using ordnance *o* where $K_{o|ta} = \frac{1}{J_{o|ta}}$, and $J_{o|ta}$ is the "*expected number of sorties for a desired fractional damage," using ordnance o, given target ta* [Ref. 8:Appendix A];

$Z_{a,Alert,xy,t}$ =

$$\left\{ \begin{array}{l} 1 \\ \quad \text{for sortie aircraft a, Alert status,} \\ \quad \text{point x,y, and time t;} \\ 0; \end{array} \right\}$$

and subscripts are:

F_i = Forward Air Controller, i = 1,2,3 . . . ;

ta = target type, e.g., tanks, infantry, armored personnel carriers, etc.;

o = ordnance type, e.g., Mk-82, Mk-83, etc.;

o|ta = ordnance type o given target type ta;

a = aircraft type, F/A-18D or AV-8B;

Alert = alert status, ground or air alert;

x,y = Cartesian coordinates for points in a battlefield area;

t = time in minutes elapsed from a reference time.

The indicator variable *Z* for ground alert aircraft is calculated as follows:

$$Z_{a,GA,xy,t} =$$

$$\left\{ \begin{array}{l} 1 \text{ if } \left\{ \begin{array}{l} 2 * \frac{d_{B_i \to xy}}{kias_{a,\max}} + L^* \leq Range_a; \text{ and,} \\ t' + tk + \frac{d_{B_i \to xy}}{kias_{a,k}} \leq t \end{array} \right\} \\ 0 \text{ otherwise;} \end{array} \right\} \qquad \forall x, y, t, a, i$$

where

$d_{B_i \to xy}$ = distance from base B_i to point x,y, i = 1,2,3 . . .;

$Range_a$ = maximum flight endurance time for aircraft a, expressed in minutes of flight, e.g., $Range_{F/A-18D}$ = 103 minutes;

$kias_{a,k}$ = knots indicated air speed for aircraft a for flight type k, where a = F/A-18D or AV-8B, and k = *del* (ordnance delivery speed or *max* (maximum endurance speed), e.g., $kias_{AV-8B,\max}$ =230;

B_i = aircraft base i, i = 1,2,3 . . . , where B_i is a x,y pair of Cartesian coordinates;

tk = time (in minutes) required for ground alert aircraft to get airborne after receiving a mission, tk = 1,2, . . .;

t' = clock time (in minutes from t = 0) an aircraft in ground or air alert status receives a mission.

The indicator variable for air alert aircraft is calculated as:

$$Z_{a,AA,xy,t} =$$

$$\left\{ \begin{array}{l} 1 \text{ if } \left\{ \begin{array}{l} \frac{d_{OP \to xy}}{kias_{a,del}} + \frac{d_{xy \to B}}{kias_{a,max}} + L^* \leq Range_a - t + t_{DEP}, \text{ and,} \\ t' + \frac{d_{OP \to xy}}{kias_{a,k}} \leq t; \end{array} \right. \\ 0 \text{ otherwise;} \end{array} \right\}$$

$$\forall (x,y), t, a;$$

where

t_{DEP} = clock time of aircraft departure for designated orbit point;

$d_{OP \to xy}$ = distance from the aircraft's orbit point to point x,y.

VII. APPLICATION

This chapter demonstrates, in four parts, the calculation and display of the combat power potential surface for close air support in a fictitious battlefield scenario. In the first part, the scenario and assumptions used to generate the surfaces are described. In subsequent parts, surfaces are generated for three areas: FAC placement on the battlefield, FAC terminal guidance method, and aircraft basing decisions.

A. SCENARIO AND ASSUMPTIONS

In this scenario, a Marine Expeditionary Force Forward (MEF FWD) has been assigned the mission of blocking and destroying an enemy unit which intelligence has located traveling north toward a pass through the mountains. This enemy unit is a combined armor-mechanized infantry force of brigade size with three principal target types: tanks, APCs, and infantry. The terrain chosen for this confrontation is an approximately 11x11 kilometer region of the California high desert. Elevations range from 1350 feet above sea level at the valley floor, sloping upward, gently at first, to 1400 feet, and then rising sharply on either side to 2000 feet. See Figure 8.

The ground combat elements of the MEF FWD are located astride the narrowest portion of the valley, across the

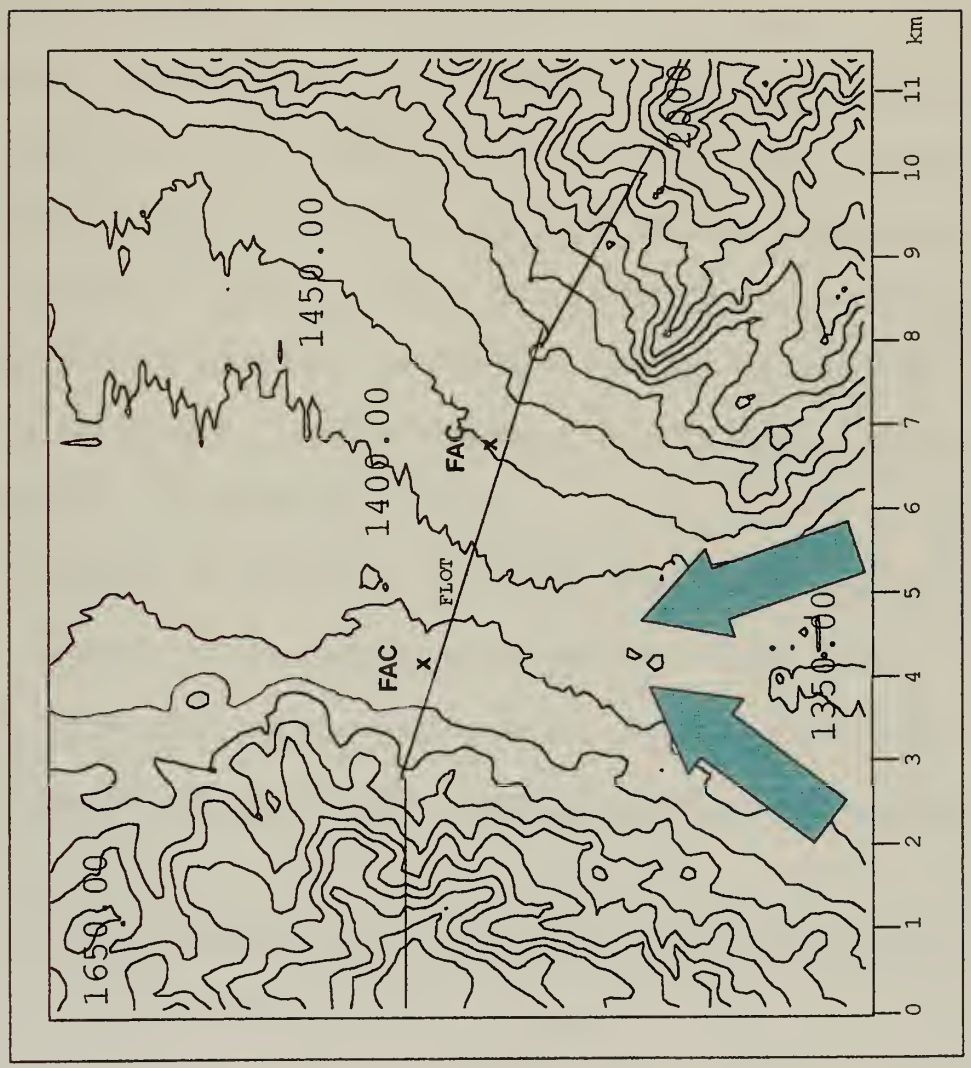


Figure 8. Battle Area.

valley floor and on the elevated terrain on either side (FLOT). Fields of fire are located southward in the shallow depression of the valley center, where the enemy force is expected to appear.

In preparing the graphical displays of a combat power potential surface, certain assumptions were made. In order to preserve the unclassified character of this thesis, the data resident in the *JMEM/AS* was not consulted. Rather than proceeding through the eight step process of Chapter III (which requires stipulating a *damage criterion*, and *desired probability of damage*), values for "number of sorties to kill" a tank, APC, or infantryman, were directly conjectured and have no firm empirical basis:

- number of sorties to kill a tank ($J_{o|ta}$) = 1.5;
- number of sorties to kill an APC = 1.2;
- number of sorties to kill an infantryman = .75;

Other values the model requires were stipulated as follows:

- tk = 5 minutes for ground alert aircraft to get airborne after mission receipt;
- t' = 0, the clock time a CAS mission is received;
- t_{DEP} = 0, clock time of aircraft departure for an orbit point;
- visibility factor = .99;

- threat factor = .9;
- pilot proficiency = .9;
- number of sorties available for the next 24 hour period = 20;
- fraction of tanks in enemy force = .05;
- fraction of APCs in enemy force = .05;
- fraction of infantrymen in enemy force = .9.

("Fraction of infantrymen" is measured in individual soldiers. Therefore, the enemy force has about 18 dismounted infantry for every tank and APC.)

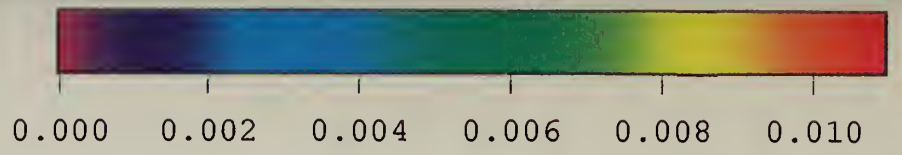
B. FAC PLACEMENT

One area where the combat power potential surface display can assist tactical decision-makers is that of the tactical emplacement of FACs. In order to situate the two FACs (for the sake of presentational simplicity, only two FACs were used in this scenario instead of the usual MEF FWD complement of four) where they have the best vantage points on the enemy avenue of approach, graphical displays of combat power potential can be employed using different FAC locations. Both FACs are using range and bearing estimates from their locations (Method A) to guide attacking aircraft rather than laser target designators (with one exception, see **C** below).

The best locations for the FACs may be determined by a simple map study (see Figure 8). This study suggests that the most advantageous place to locate them appears to be on the highest points overlooking the valley, the 1900 ft. peak on the left for one FAC and the 2000 ft. peak on the right for the second FAC. Figure 9 indicates, however, that PP_{CAS} is rather limited with this deployment: with red indicating the highest PP_{CAS} and purple the lowest (in effect, zero combat power potential), each FAC has only limited PP_{CAS} when situated on the peaks, with almost all of it on the steep valley sides opposite to each location.

This limitation is largely due to the restricted lines-of-sight obtainable from these peaks, as evidenced by the predominance of purple (i.e., zero power potential) in the surface. Were the principal cause of the low PP_{CAS} *distance from each FAC*, a greater range of color (from red to purple) would be visible as FAC effectiveness tapered off with increasing distance.

By re-locating the FACs to the slightly elevated shoulders of the valley (1400 ft.), the PP_{CAS} is considerably improved, as shown in Figure 10. Located at these lower points, the FACs have considerably higher PP_{CAS}, extending two to three kilometers forward of their positions.



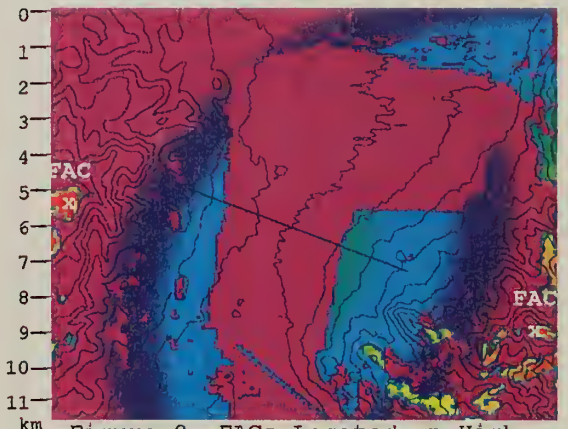


Figure 9. FACs Located on High Ground.

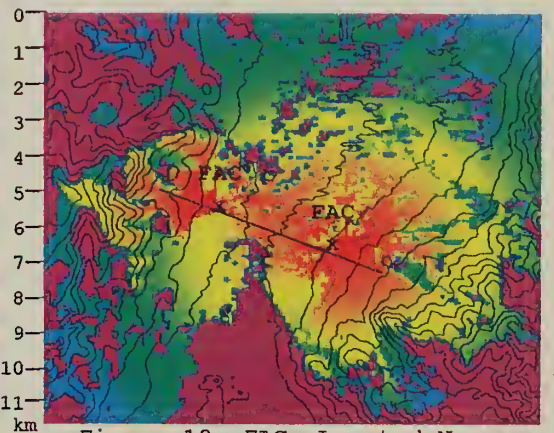


Figure 10. FACs Located Near Valley Floor.

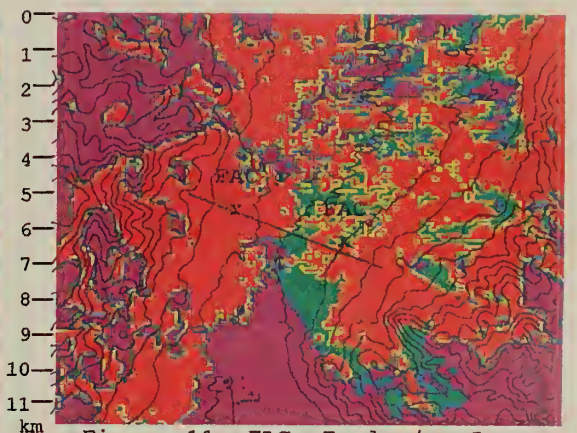


Figure 11. FACs Employing Laser Target Designators.

C. FAC TERMINAL GUIDANCE METHOD

Varying the method of target designation by the FACs also produces a considerably different battlefield picture. Contrast Figures 10 and 11: the former was generated assuming the FACs employed subjective range and bearing estimates, while the latter assumes the use of laser target designation. Note that, although there is no area expansion of the power potential surface when lasers are used, those areas that the FACs can see have a considerably higher power potential in Figure 11 than in Figure 10. This is indicated by the preponderance of deep red in areas that were formerly light red, yellow, or green. Put another way, the bulk of power potential degradation shown in Figure 10 can be attributed to distance judgments errors on the part of the FACs.

D. BASING DECISIONS

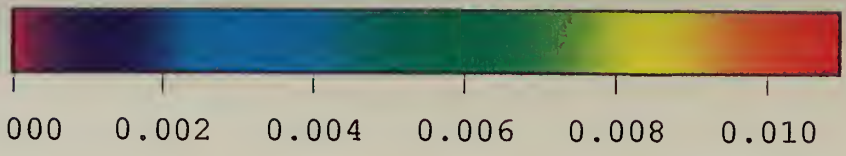
By varying time *t*, the combat power potential surface can also show the battlefield impact of decisions on aircraft basing, whether to base CAS aircraft aboard ships, ashore, or even in a neighboring friendly country (this last alternative is not explored here).

Consider first the decision to base all CAS aircraft aboard amphibious vessels and carriers located e.g., 31 miles (50 km) north of the operations area, or about 35 miles (56 km) north of the FLOT. Of principal concern to a

MEF FWD Commander would be the timeliness and sustainability of CAS in the battle area, particularly in light of their shipboard basing. To address these concerns, graphical displays can be used to reveal the combat power potential of CAS available at various t (Figures 12, 13, and 14). These displays indicate that, under the assumption that all aircraft are ship-based, CAS would be available at the FLOT to a ground commander by t = 20 minutes (Figure 13) after receipt of a CAS mission, and over the enemy avenue of approach by t = 22 (Figure 14). While this time lag may be accounted for in scheduling pre-planned missions and need not present a serious problem for these types of missions, it may be intolerable for on-call missions. Under these circumstances, CAS is not timely, but it is sustainable.

One way to reduce this time lag is to put CAS aircraft in an air alert status in orbit points in proximity to the FLOT, thereby reducing their response time. Assume that CAS aircraft are placed in orbit points approximately 5.5 km behind the FLOT. Figure 15 shows that CAS is available over the enemy avenue of approach by t = 2, but Figure 16 indicates that the reach of CAS begins to degrade by t = 80 (Figure 16), and does not extend beyond the FLOT by t = 82 (Figure 17). CAS is now timely, but may not be sustainable.

One solution is a mix of ship- or airfield-based (ground alert) aircraft and air alert aircraft in local



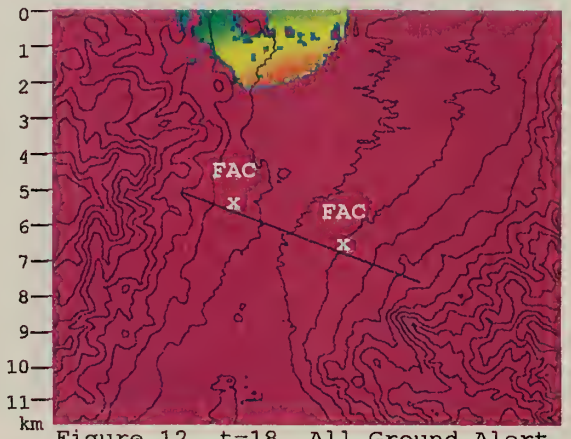


Figure 12. t=18, All Ground Alert, ship-based.

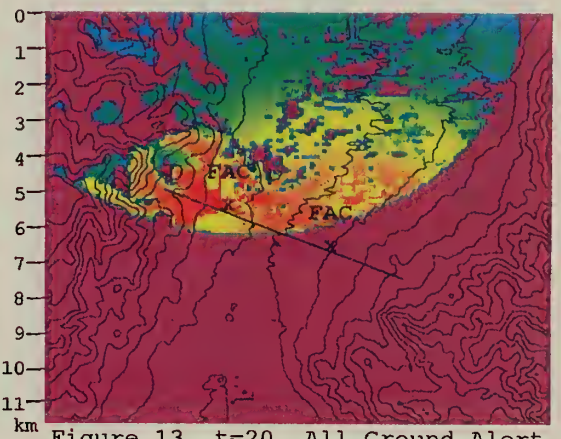


Figure 13. t=20, All Ground Alert ship-based.

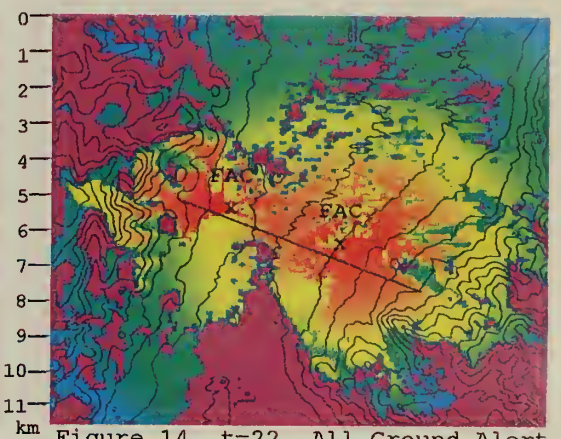
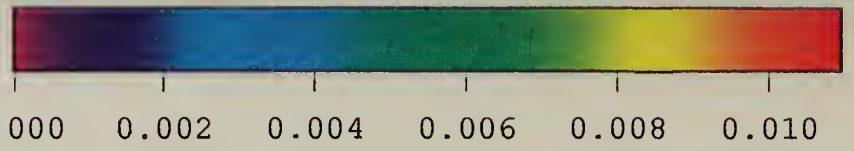


Figure 14. t=22, All Ground Alert, ship-based.



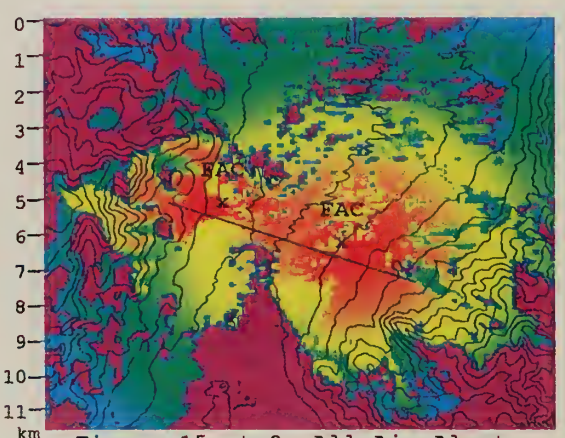


Figure 15. t=2, All Air Alert.

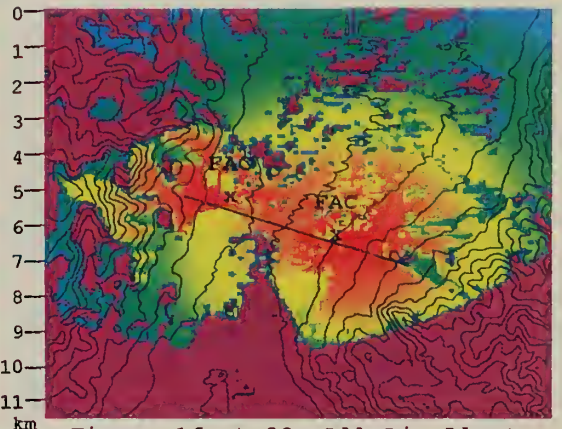


Figure 16. t=80, All Air Alert.

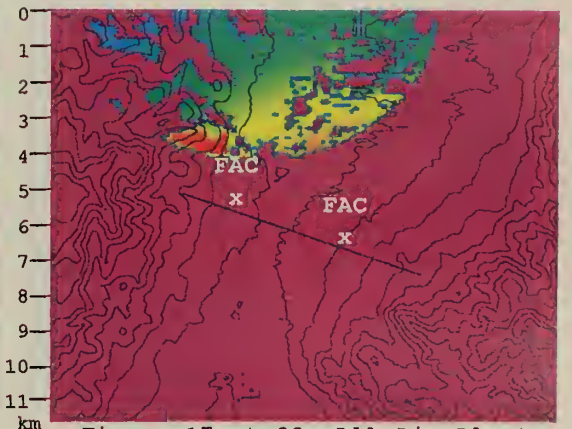
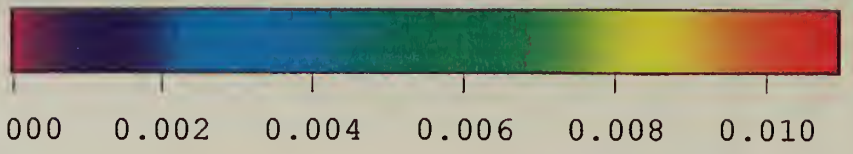
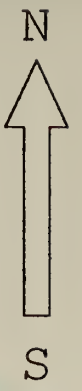


Figure 17. t=82, All Air Alert.





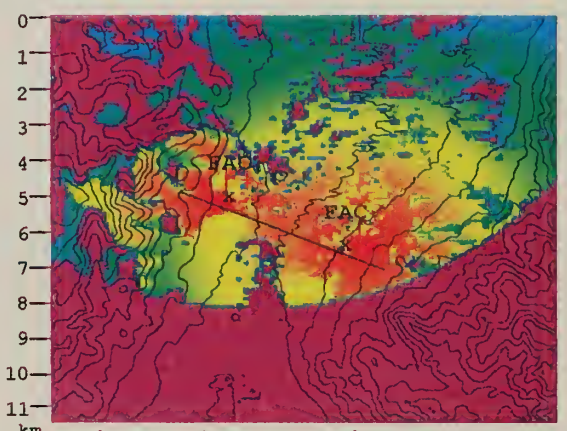


Figure 18. t=1, Air and Ground Alert.

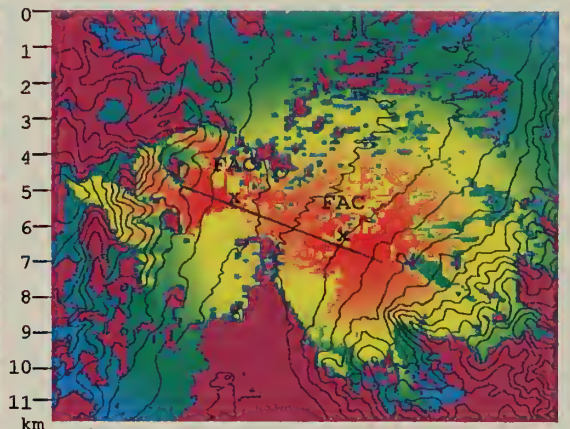


Figure 19. t=2, Air and Ground Alert.

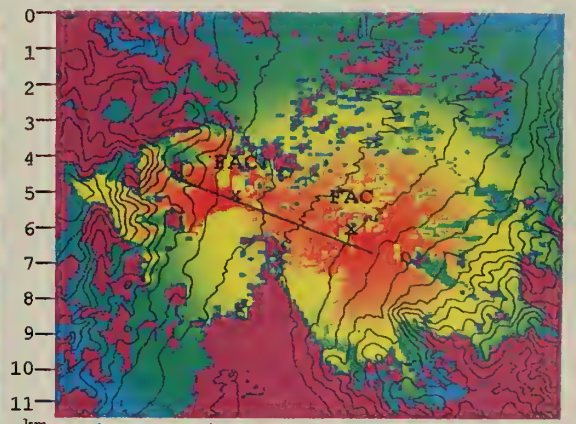


Figure 20. t=83, Air and Ground Alert.

orbit points. In this arrangment, CAS is partially available forward of the FLOT as early as t = 1 minute (Figure 18), is fully available at t = 2 minutes (Figure 19), and is still fully available as late as t = 83 minutes (Figure 20).

This chapter demonstrates some of the capabilities of the graphical display of combat power potential for CAS. Many more variables in the model could be changed, revealing graphically the impact these variables could have on the battlefield.

VIII. CONCLUSION

In conclusion, two points can be made.

First, the model developed here is *deterministic* rather than *stochastic*. The random occurrences that typically mark air warfare are not explicitly included. For instance, no attempt has been made to model unforeseen aircraft mechanical failures that have a negative impact on aggregated air power. The model assumes that once an ACE commander determines how many aircraft sorties he can dedicate to CAS for a 24 hour period, he will provide that number. Aircraft failures (or casualties) will only be reflected in the number of sorties available for the next 24 hour planning period.

It is important to note that this exclusion of random changes in air power does not extend to immediate CAS missions. This is not because the model possesses stochastic elements; as already stated, the model is deterministic. Rather, immediate CAS requests, though random by definition, result in neither a diminution nor amplification of total airpower available to support the ground war. Such requests simply divert CAS aircraft from one specific mission to another. This has no effect on the *combat power potential* of CAS, which by definition is the capacity to deliver lethal fire throughout the battlefield at any time. CAS mission diversion actualizes potential at

another battlefield point without altering capacity, i.e., combat power potential.

Second and last, the aim of this thesis is to assist the MAGTF Commander and his staff in visualizing the battlefield through time by allowing them to see how tactical decisions impact on the ability to mass force. It neither supplants military judgment and expertise, nor provides a "how to win battles" computer tutorial. The algorithm for computing CAS combat power potential presented in this thesis has been constructed, as much as possible, out of the objective, physical capabilities and limitations of CAS aircraft and aircrews. The many intangible factors that influence, and may even decide, combat, e.g., morale, fear, the mental attitude of opposing commanders, etc., are beyond the scope of this algorithm, and probably beyond any computer calculation.

Nevertheless, by allowing a MAGTF Commander to "see" at a glance where and when on the battlefield he can bring combat power to bear, the visualization aimed at in this thesis can free him to consider those intangibles all the more.

APPENDIX. JAVA APPLICATION TO CALCULATE COMBAT POWER POTENTIAL IN A FICTITIOUS BATTLE SCENARIO

```
/**
 *Modelling the Combat Power Potential of Marine Corps CAS
 *
 *This program reads in map data (terrain points and
 *associated elevation) from a 2 dimensional array data
 *structure and computes the expected kills per minute
 *achievable at each point by Marine Corps close air support
 *aircraft, the F/A-18D and AV-8B, given specified
 *battlefield conditions, base locations, locations of two
 *Forward Air Controllers (FACs), aircraft alert status,
 *etc. The resulting value, the power potential of CAS, is
 *outputted to a file.
**/

import java.io.*;
public class PowerCAS {
  //class constants
    private static final int MAXFLIGHT = 101; //max flight
                                              //time
    private static final int DAYMINUTES = 1440; // 60 min *
                                                //24 hrs
    private static final int KIASDEL = 500; //speed of
                                            //ordnance delivery
    private static final int KIASMAX = 240; //maximum
                                             //endurance speed
    private static final int LOITER = 5; //minimum required
                                         //loiter time
    private static final int SCALE = 10;//max useful
                                        //distance for FACs
    private static final double POWER = 1.25;//used to
                                     //calculate FAC degradation
    private static final double CELL = .09;//each map cell
                                           //is .09x.09 km
    private static final int ARRAYSIZE = 125;//2-D array
                                             //size
    private static final int FACHEIGHT = 3;//FAC's height
                                           //above ground
    private static final int TGTHEIGHT = 5;//Target height
                                           //above ground
    private static final int ELEVARRAY = 1000;//max possible
                                            //size elev array
    private static final int DELTABASE = 50;//add to base
                                            //distance
    private static final int DELTAORBIT = 0;//add to orbit
                                            //distance
```

```
//class variables
  private static double visibility; // visibility
                                    //degradation factor
  private static double threat;  //threat degradation
                                 //factor
  private static double pproficiency; //pilot proficiency
                                      //degradation factor
  private static double sortiestank; //expected no. of
                                     //sorties to achieve
                                     //desired damage of
                                     //tank target
  private static double sortiesbmp;  //expected no. of
                                     //sorties to achieve
                                     //desired damage for
                                     //enemy bmp
  private static double sortiesinfantry;//expected no. of
                                        //sorties to achieve
                                        //desired damage on
                                        //infantry target
  private static double numsorties;  //no. of CAS sorties
                                    //available for 24 hours
  private static int basex;        //airbase x coordinate
  private static int basey;        //airbase y coordinate
  private static int orbitx;       //x coord of air alert
                                   //aircraft orbit point
  private static int orbity;       //y coord of orbit point
  private static double ftanks;    //fraction of enemy force
                                   //made up of tanks
  private static double fbmps;     //fraction of enemy force
                                   //made up of bmps
  private static double finfantry;//fraction of enemy force
                                  //made up of infantry

//instance variables
  private int strike;       //1 if can strike point x,y; 0
                            //otherwise
  private int lineOfSight1; //1 if line of sight from FAC1
                            //to x,y; 0 otherwise
  private int lineOfSight2; //1 if line of sight from FAC2
                            //to x,y; 0 otherwise
  private double distoBase; //point's distance to airbase
  private double distoOrbit;//point's distance to orbit
                            //point of aircraft
  private double distoFac1; //point's distance to FAC1
  private double distoFac2; //point's distance to FAC2
  private double pwrpotent; //expected kills per minute at
                            //point x,y
  private double elevation; //elevation at point x,y
  private double x;         //x coordinate of grid point
```

```
  private double y;          //y coordinate of grid point
  private double acquire1;   //FAC1 degradation factor for
                             //point x,y
  private double acquire2;   //FAC2 degradation factor for
                             //point x,y


//constructor method
  public PowerCAS (double r, double c, double e) {
   strike = 0;
   lineOfSight1 = 0;
   lineOfSight2 = 0;
   distoBase = Double.POSITIVE_INFINITY;
   distoOrbit = Double.POSITIVE_INFINITY;
   distoFac1 = Double.POSITIVE_INFINITY;
   distoFac2 = Double.POSITIVE_INFINITY;
   pwrpotent = 0.0;
   elevation = e;
   x = r;
   y = c;
   acquire1 = 0;
   acquire2 = 0;
  }

//instance methods
  //getter methods
    public double getFac1distance() {return distoFac1;}
    public double getFac2distance() {return distoFac2;}
    public double getdistoBase(){return distoBase;}
    public double getdistoOrbit(){return distoOrbit;}
    public int getlineOfSight1(){return lineOfSight1;}
    public int getlineOfSight2(){return lineOfSight2;}
    public int getStrike(){return strike;}
    public double getAcquire1(){return acquire1;}
    public double getAcquire2(){return acquire2;}

  //setter methods
    public void setStrike(int s){
      strike = s;
    }
    public void setLOS1 (int los){
      lineOfSight1 = los;
    }
    public void setLOS2 (int los){
      lineOfSight2 = los;
    }

    /*
```

```
 This method, as well as the three methods that follow
 it, sets the instance point's distance from an
 aircraft base by calling the "range" method for the
 x,y distance, and then multiplying the resulting value
 by the size of the cells in the DTED map, .09
 kilometers (90 meters), to obtain distance in
 kilometers.  The constant DELTABASE is added
 to situate a base at a specific distance from the
 terrain sector under consideration, i.e., off the map.
*/

public void setBasedistance(int basex, int basey){
  distoBase = DELTABASE + CELL * (range(basex,basey));
}

/*
 This sets the instance point's distance from an
 aircraft orbit point.
*/

public void setOrbitdistance(int orbitx, int orbity){
  distoOrbit = DELTAORBIT + CELL *
                              (range(orbitx,orbity));
}

/*
 This sets the instance point's distance from FAC #1
*/

public void setFac1distance(int facx, int facy) {
  distoFac1 = CELL * (range(facx,facy));
}

/*
 This sets the instance point's distance from FAC #2
*/

public void setFac2distance(int facx, int facy) {
  distoFac2 = CELL * (range(facx,facy));
}
public void setAcquire1(double a){
  acquire1=a;
}
public void setAcquire2(double a){
  acquire2=a;
}
```

```
/*
 ****************************************************
  This method calculates the x,y range between two
  points.
 ****************************************************
*/

  public double range(int ex, int wy){
    double changex = ex - x;
    double changey = wy - y;
    return Math.sqrt(changex*changex + changey*changey);
  }

/*
 ****************************************************
 This method determines whether line of sight exists
 between the instance point (x,y) and the locations of
 the two FACs. The if-else loop's two portions are mirror
 images of each other, depending on whether the y
 dimension between the x,y and the FAC is larger or the x
 dimension is larger. This method owes its form to the PV
 Wave Command Language Procedures of Reference 27, pages
 29-34.
****************************************************
*/

  public void figureLOS(double [][] gridArray,
                                      int[][]facArray){
    double elevFAC, elevPT, yincrement, yaccumulator,
           xincrement, xaccumulator, zincrement,
           numLOStests, LOSline, terrain;
    int counter, xcell, ycell, increment, deltax, deltay,
        facx, facy,i,j;
    boolean obstacle;
    double elevArray[] = new double [ELEVARRAY];
    i = 0;
    j = 0;
    while (i <= 1) {
      counter = 0;
      facx = facArray[i][j];
      j = j + 1;
      facy = facArray[i][j];
      if (facx == x && facy == y) {     //if the point and
                                        //the FAC occupy
          if (i == 0) {                 //the same cell,
                                        //LOS is presumed
              setLOS1(1);               //to exist
          }
```

```
        else {
            setLOS2(1);
        }
    }
    else {
       deltax = (int)Math.abs(x-facx);
       deltay = (int)Math.abs(y-facy);
       if (deltay < deltax) {          //step in x
                                       //direction
           if (x < facx) {             //point is to left
                                       //of FAC
               increment = -1;
           }
           else  {
               increment = 1;          //point is to right
                                       //of FAC
           }

           yincrement = (y - facy)/deltax;//slope
                                        //of line between
                                        //x,y and FAC
           yaccumulator = facy;

           //this for loop collects the elevations of
           //all cells between the x,y and the FAC

           for (xcell = facx; xcell != x; xcell = xcell
                                          + increment) {
                ycell = (int)yaccumulator;
                elevArray[counter] =
                                gridArray[xcell][ycell];
                yaccumulator = yaccumulator +
                                             yincrement;
                counter = counter + 1;
           }
       }
       else {                                //step in
                                             //y direction
           if (y < facy) {                   //point is
                                             //"below" FAC
               increment = -1;
           }
           else {                            //point is
                                             //"above" FAC
               increment = 1;
           }

           xincrement = (x - facx)/deltay;
```

```
            xaccumulator = facx;
            for (ycell = facy; ycell != y; ycell = ycell
                                        + increment) {
                xcell = (int)xaccumulator;
                elevArray[counter] =
                                gridArray[xcell][ycell];
                xaccumulator = xaccumulator +
                                            xincrement;
                counter = counter + 1;
            }
        }   //end inner if loop
    }       //end outer if loop
    elevFAC = elevArray[0] + FACHEIGHT;
    elevPT =  elevation + TGTHEIGHT;
    numLOStests = counter - 1;    //don't check point
                                  //cell elevation
    zincrement = 0.0;
    zincrement = (elevPT - elevFAC)/(counter - 1);
                                   //slope of LOS line
    LOSline = elevFAC;
    obstacle = false;
    int ctr;

    //this for loop compares each intervening cell
    //elevation with the elevation of the LOS line
    //between x,y and FAC

    for (ctr = 1; ctr <= numLOStests; ctr++) {//test
                                  //all points between
            LOSline = LOSline + zincrement;
            terrain = elevArray[ctr];
            if (LOSline <= terrain) {
                obstacle = true;
                if (i == 0) {
                    setLOS1(0);
                }
                if (i == 1) {
                    setLOS2(0);
                }
            }
    }     //end for loop
    if (obstacle == false && i == 0) {
        setLOS1(1);
    }
    if (obstacle == false && i == 1) {
        setLOS2(1);
    }
i = i + 1;
j = 0;
```

```
  } // end while loop
}   //end method

/*
 ************************************************
 this method determines whether the x,y point can be
 reached by aircraft in air alert and/or ground alert,
 depending on aircraft status as set by the user
 ************************************************
*/
public void figureStrike(double t, double tk, double
                         tprime, double tdep,
                         boolean air, boolean ground){

  int counter, groundstrike, airstrike;
  groundstrike = 0;
  airstrike = 0;
  if (ground == true) {
      if (2*distoBase/(KIASMAX/60) + LOITER <=
          MAXFLIGHT && tprime + tk +
          distoBase/(KIASMAX/60) <= t) {
          groundstrike = 1;
      }
      else  {
          groundstrike = 0;
      }
  }
  if (air == true) {
      if (distoOrbit/(KIASDEL/60) +
           distoBase/(KIASMAX/60) + LOITER <= MAXFLIGHT
          - t + tdep && tprime +
                        distoOrbit/(KIASDEL/60) <= t) {
          airstrike = 1;
      }
      else  {
          airstrike = 0;
      }
  }
  if (groundstrike == 1 || airstrike == 1) {
      setStrike(1);
  }
  else {
      setStrike(0);
  }
}

/*
 ************************************************
```

```
 this method determines the degradation to CAS
 effectiveness caused by the FAC's distance from the
 point; if the FAC is using laser target
 designators, strike is set to one; if he is relying on
 subjective judgments of range and bearing to the
 target from his positions, the amount of degradation
 is calculated as shown
 ********************************************
*/

public void facdegrade (boolean laser) {
  if (laser == true) {
      setAcquire1(1);
      setAcquire2(2);
  }
  else {
       if (getlineOfSight1() == 1 && getlineOfSight2()
                                                  == 1){
           if(getFac1distance() <= getFac2distance() &&
                          getFac1distance() < SCALE){
              setAcquire1(1 -
              Math.pow(getFac1distance()/SCALE,POWER));
           }
           if(getFac1distance() > getFac2distance() &&
                          getFac2distance() < SCALE){
              setAcquire2(1 -
              Math.pow(getFac2distance()/SCALE,POWER));
           }
           if(getFac1distance() > SCALE) {
              setAcquire1(0);
           }
           if(getFac2distance() > SCALE) {
              setAcquire2(0);
           }
       }    // end if loop
       if (getlineOfSight1() == 1 && getlineOfSight2()
                                                  == 0) {
           if(getFac1distance() < SCALE) {
              setAcquire1(1 -
            Math.pow(getFac1distance()/SCALE, POWER));
              setAcquire2(0);
           }
           else {
              setAcquire1(0);
              setAcquire2(0);
           }
       }
       if (getlineOfSight1() == 0 && getlineOfSight2()
                                                  == 1) {
```

```
            if(getFac2distance() < SCALE) {
               setAcquire1(0);
               setAcquire2(1 -
              Math.pow(getFac2distance()/SCALE, POWER));
            }
            else {
               setAcquire1(0);
               setAcquire2(0);
            }
         }
    }  // end else
  }    // end method

  /*
   ***********************************************
   this method calculates the final value, "expected
   kills per minute", for each instance point. If both
   FACs have LOS to the point, the higher value is
   returned
   ***********************************************
  */

  public double calcPPCAS() {     //calculates expected
                                  //kills per minute
    double r, sum, temp1, temp2;
    r = numsorties/DAYMINUTES;
    sum = ftanks/sortiestank + fbmps/sortiesbmp +
          finfantry/sortiesinfantry;
    temp1 = visibility*lineOfSight1*acquire1*threat*
            pproficiency*strike*r*sum;
    temp2 = visibility*lineOfSight2*acquire2*threat*
            pproficiency*strike*r*sum;
    if (temp1 > temp2) {
        return temp1;
    }
    else {
        return temp2;
    }
  }

//main method
  public static void main (String argv[]) throws
                                          IOException {
    int laser, A, G, row, column, i, j;
    boolean L, air, ground;
    double t, tk, tprime, tdep;
    double gridArray[][];           //this array
                                    //collects elevations
```

```
int facArray[][] = new int [2][2]; //this array holds
                                   //FAC locations
System.out.println("begin working . . . .");
FileInputStream infile1 = new
                        FileInputStream("inputs.txt");
StreamTokenizer tokens1 = new
                            StreamTokenizer(infile1);
 tokens1.nextToken();
 for(i = 0; i <= 1; i++) {
   for (j = 0; j <= 1; j++) {
     facArray[i][j] = (int)tokens1.nval;
     tokens1.nextToken();
   }
 }
 t = tokens1.nval; tokens1.nextToken(); // clock time
 tk = tokens1.nval; tokens1.nextToken(); // time to
                                         //get airborne
 tprime = tokens1.nval; tokens1.nextToken(); //clock
                                   //time mission rec'd
 tdep = tokens1.nval; tokens1.nextToken(); // time of
                                   //aircraft departure
 A = (int) tokens1.nval;tokens1.nextToken();
                                 //aircraft in air alert
 G = (int) tokens1.nval; tokens1.nextToken();
                               //aircraft in ground alert
 visibility = tokens1.nval; tokens1.nextToken();
 threat = tokens1.nval; tokens1.nextToken();
 pproficiency = tokens1.nval; tokens1.nextToken();
 sortiestank = tokens1.nval; tokens1.nextToken();
 sortiesbmp = tokens1.nval; tokens1.nextToken();
 sortiesinfantry = tokens1.nval; tokens1.nextToken();
 numsorties = tokens1.nval; tokens1.nextToken();
 basex = (int)tokens1.nval; tokens1.nextToken();
 basey = (int)tokens1.nval; tokens1.nextToken();
 orbitx = (int)tokens1.nval; tokens1.nextToken();
 orbity = (int)tokens1.nval; tokens1.nextToken();
 ftanks = tokens1.nval; tokens1.nextToken();
 fbmps = tokens1.nval; tokens1.nextToken();
 finfantry = tokens1.nval; tokens1.nextToken();
 laser = (int)tokens1.nval;
infile1.close();
System.out.println("read in input file . . .");
gridArray = new double [ARRAYSIZE][ARRAYSIZE];
FileInputStream infile = new
                     FileInputStream("E:/warmap.txt");
StreamTokenizer tokens = new StreamTokenizer
                                              (infile);
System.out.println("begin reading in map array . .");
for (row = 0; row < ARRAYSIZE; row++)  {
```

```
 for (column = 0; column < ARRAYSIZE; column++) {
  tokens.nextToken();
  gridArray[row][column] = tokens.nval;
 }
}
infile.close();
System.out.println("done reading in map array . . ");
FileOutputStream outfile = new
                    FileOutputStream("E:/PPCAS.txt");
PrintStream output = new PrintStream(outfile);
System.out.println("begin calculating power potential
                                              . . . ");
for (row = 0; row < ARRAYSIZE; row++)  {
 for (column = 0; column < ARRAYSIZE; column++) {
  PowerCAS p = new PowerCAS(row, column,
                            gridArray[row][column]);
  p.setBasedistance(basex, basey);
  p.setOrbitdistance(orbitx,orbity);
  if (laser == 1) {  //if the FAC is using laser
                     //target designator
      L = true;
  }
  else {
      L = false;
  }
  p.figureLOS(gridArray, facArray);
  p.setFac1distance(facArray[0][0], facArray[0][1]);
  p.setFac2distance(facArray[1][0], facArray[1][1]);
  p.facdegrade(L);
  if (A == 1) {      //if aircraft are in air alert
                     //status
      air = true;
  }
  else {
      air = false;
  }
  if (G == 1) {      //if aircraft are in ground
                     //alert status
      ground = true;
  }
  else {
     ground = false;
  }
  p.figureStrike(t, tk, tprime, tdep, air, ground);
  if (column == ARRAYSIZE - 1) {
      output.println(p.calcPPCAS());
  }
  else {
      output.print(p.calcPPCAS() + " ");
```

```
            }
          }      //end inner for loop
        }        //end outer for loop
        output.close();

    }                                   //end main method
}                                       //end program
```

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